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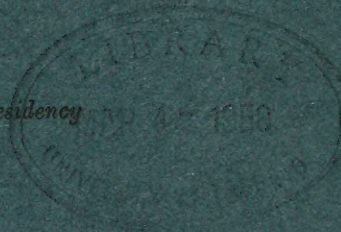
STUDIES IN INHERITANCE IN COTTON, I

HISTORY OF A CROSS BETWEEN *GOSSYPIMUM HERBACEUM* AND *GOSSYPIMUM NEGLECTUM*

BY

G. L. KOTTUR, M.Ag

Cotton Breeder, Southern Maratha Country, Bombay Presidency



AGRICULTURAL RESEARCH INSTITUTE, PUSA

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BY

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STUDIES IN INHERITANCE IN COTTON, I.

HISTORY OF A CROSS BETWEEN *GOSSYPIUM HERBACEUM* AND *GOSSYPIUM NEGLECTUM*

BY

G. L. KOTTUR, M.AG.,

Cotton Breeder, Southern Maratha Country, Bombay Presidency.

[Received for publication on 1st November, 1922.]

I. INTRODUCTION.

ATTEMPTS to increase the value of the cotton plant grown in India or the value of the cotton produced, by means of the crossing of different species or different varieties of the cotton plant, date almost from the beginning of serious work on cotton improvement in the early years of the present century. And it is natural that this should have been a favourite way of tackling the problem, for there are such a large number of species grown in India, each with its special advantages and disadvantages, that hardly any species can be considered as really satisfactory from both the grower's and the merchant's point of view. For instance, the types derived from *Gossypium neglectum* are high yielding, high ginning, and easily grown, but are nearly always poor in staple—the poorest in fact of any types of cotton actually in cultivation. *Gossypium indicum*, though of excellent staple, yields poorly and has a low ginning percentage. *Gossypium herbaceum*, though cultivated over large areas, usually requires a long growing period and is hence difficult to grow, while its staple varies very widely, and in the cultivated types good staple seems to be almost always joined to low ginning percentage. It appears, at first sight, in fact, that if the valuable characters attached to each of these species could be combined with those derived from one of the others, an almost ideal cotton plant for almost any area could be obtained.

The crossing in question is not, however, nearly so simple, as appears at first sight, for all the varieties are polymorphic, being made up of a number

of distinct strains which have a different botanical and agricultural value. This polymorphic character of the crop, together with the fact that natural crossing occurs in the field to a limited extent, has two effects. It makes selection of the best of the strains a more easily applied method of improvement, and it makes the effect of crossing less easily determinable, especially when a parent is itself a hybrid between several of the strains in the crop. Hence, though a very large number of crosses were made in the years before 1907, they were almost all abandoned as giving types of too inconstant and too unsatisfactory a character, very soon after they had been produced. And, as a result, selection of the most valuable strains in the crops ordinarily grown has been almost exclusively relied upon for cotton improvement in the last twelve or fourteen years.

But it is obvious that the limits of improvement by selection alone, however carefully done, are very narrow. The best types can be isolated and grown pure, and this is usually an immense advantage, for the growing of a mixture of strains of unequal value is always unprofitable. But beyond the limit set by the types already existing, or the chance occurrence of a valuable mutation in the growing crop, no breeder can go without actual crossing of types.

Hence, as has already been said, crossing has been often attempted but the results of the crosses have rarely been carried so far as to get into actual cultivation. In the early days before 1907 when a large number of crosses were made in a somewhat haphazard and empirical fashion, the most important result was to show that the various Indian cottons cross freely with one another, and that, as would be expected, the immediate effect of crossing is to lead to considerably increased vigour in the plants. These facts were soon discovered by the workers on the subject, and as a result, in Bombay for instance, during the years between 1901 and 1907¹ crosses were made between the *broach*, *kumpta*, and *goghari* varieties of *Gossypium herbaceum*, the Dharwar-American, and the Cambodia varieties of *Gossypium hirsutum* and others. These were combined in almost every possible way with the object of inducing variability and then selecting desirable variations. But although careful selection was made for a number of years the crosses obtained usually proved unprofitable. The necessary precautions such as the protection of the plants from natural crossing were not taken, and the crosses were made without recognizing that each variety of cotton is itself a mixture of many types. Moreover, mass selection was adopted, too early, even before the strains obtained were fixed

¹ Kulkarni and Kottur. Improvement of Cotton in the Bombay Presidency. *Bull. No. 70. Dept. of Agri., Bombay (1915).*

Generally, therefore, the result was neither to obtain the improved types desired, nor even to settle the question as to what are dominant or recessive characters when different types of cotton are crossed with one another.

The above remarks refer to the crosses made in Bombay, but the same negative results seem to have been obtained in other parts of India. In the Central Provinces a number of hybrids were produced at Nagpur and Akola in 1905 and 1906, but the fate of these is unknown. And a similar statement might be made with regard to such crossing work as was done in every province in India. The hybrids which ever passed out into general use were few, and they themselves were by no means pure. Among these may be noted the so-called "Kumpta Cross"—a hybrid between two strains of *kumpta* cotton (*Gossypium herbaceum*) made in 1901 and No. 1027 A. L. F. at Navsari in the *broach* cotton area, a type produced in 1901 by crossing the *kumpta* and *goghari* varieties of *Gossypium herbaceum*. Using similar methods, a cross between *bani* (*Gossypium indicum*) and *deshi* Lahore (*Gossypium neglectum*) termed the "Sindewahi Cross" seems to have successfully entered into general cultivation in the Central Provinces.

The first published work on the principles which lie in the basis of the successful crossing of Indian cottons for agricultural purposes was that of Fletcher,¹ who, basing his conclusions on Bombay experience, stated that, fineness, length and colour of the lint are dominant in the crosses he made, that yellow colour in the flower is dominant over white, and that fuzziness in the seed is dominant over nakedness. About the same time Balls², whose work in Egypt since that time has been of very great importance on all questions in relation to the growth and development of cotton, published his first work. The conclusions to which he came will be referred to later in considering the heredity of each factor discussed in the present paper. The work of Fyson³ followed, and was based chiefly on crosses between a *Gossypium herbaceum* (*jowari*) and a *Gossypium neglectum* (*jari*). He found that the shape of the leaf (broad-lobed and narrow-lobed) and the colour of the flowers (white and yellow) appear to segregate on Mendelian lines, yellow colour being dominant over white and the narrow lobing of the leaf being dominant over the broad lobing. Again he judged, though he did not prove, that fuzziness of the seed segregates as a Mendelian character, and that "so far as two generations

¹ Fletcher. Mendelian Inheritance in Cotton. *Jour. Agri. Sci.*, Vol. II, p. 281 (1907).

² Balls. Note on Mendelian Heredity in Cotton. *Jour. Agri. Sci.*, Vol. II, p. 216 (1907); also Mendelian Studies of Egyptian Cotton. *Jour. Agri. Sci.*, Vol. II, p. 347 (1908).

³ Fyson. Some experience in the Hybridising of Indian Cotton. *Mem. Dept. Agri. Ind., Bot. Ser.*, Vol. II, No. 6 (1908).

showed, length and fineness of the lint were dominant over the short and rough woolly nature, and the habit of the bolls opening widely dominant over that of opening a little."

The work of Balls between 1907—09 is interesting because it deals with Egyptian cotton, and hence with a species different from that with which most of the work in India has been done. He found natural crossing taking place and studied the second generation (F_2) of these crosses. He observed that long staple was completely dominant over short, thus confirming Fletcher's and Fyson's observations on other species of cotton. The inheritance of the colour of the flowers was more complex, and he was not able to elucidate its character completely. The time of ripening (*i.e.*, earliness or lateness of the type) seemed to be a Mendelian character, while "the fact that many of the most important commercial qualities are dominant Mendelian characters presages considerable difficulty in preparing improved types." Later on, he studied a large number of additional characters in crosses between American (*Gossypium hirsutum*) and Egyptian (*Gossypium barbadense*) cotton, and his conclusions may be summarized as follows.

(a) The following characters are completely dominant :—

- (1) Tallness of the main stem over shortness.
- (2) A long leaf over a short leaf.
- (3) A slightly incised leaf over a deeply incised leaf.
- (4) A broad angle between leaf lobes over a narrow angle.
- (5) A long petal in the flower over a short petal.
- (6) Large seed over small seed.
- (7) Long lint over short lint.

(b) The following characters are incompletely dominant :—

- (1) A red spot at the base of the leaf over a leaf without this spot.
- (2) Yellow colour over white colour in the flower petal.
- (3) A red spot at the base of the flower petal over a petal with no spot.
- (4) Yellow colour over white colour in the anthers.
- (5) Brown colour over absence of colour in the lint.

(c) No definite conclusion was reached with regard to the heredity of the following characters :—

- (1) Hairiness of the plant.
- (2) Shape of the stipule.
- (3) Roughness and glandulation of the boll.
- (4) Fuzziness of the seed.
- (5) Colour of the fuzz.
- (6) Distribution of lint on the seed.

We shall see later how far the author's investigations on an entirely different cross confirm these observations.

Leake's work, which was begun in 1904, and was published in a series of papers from 1908 to 1914, was based in the first instance on a much more careful examination of the manner of growth of Indian cottons than had hitherto been made, and on three crosses made between pure lines of—

- (1) *Gossypium arboreum* (narma cotton) and *Gossypium neglectum* (white-flowered *deshi*).
- (2) *Gossypium indicum* (bani cotton) and *Gossypium neglectum* (white-flowered *deshi*).
- (3) *Gossypium herbaceum* (broach cotton) and *Gossypium neglectum* (white-flowered *deshi*).

The principal work was done with the first of these as the cross between *herbaceum* and *neglectum* cotton tended to give infertile seed, and that between *indicum* and *neglectum* showed signs of weakness in the *indicum* parent. The characters studied were (1) the colour of the corolla and the presence of a spot at the base of the petal; (2) the presence or absence of red colouring matter in the sap; (3) the leaf factor; and (4) the type of branching and the length of the growing period previous to flowering. Two of these characters will be discussed fully later* in connection with the author's own crosses, namely, the colour of the corolla and the leaf factor. With regard to the other characters named above, it may be stated that presence of a spot at the base of the petal is completely dominant over its absence, that the red colour in the sap is a complex of two factors, redness and yellowness, and these segregate on Mendelian lines, and that the type of branching appears not to be inherited as a definite Mendelian character. Leake confessedly limited his papers to a discussion of the vegetative characters of the cotton plant and promised another memoir on the commercially valuable portion of the crop. This has not, however, as yet appeared.

Taking all together, therefore, the work hitherto done would seem to indicate that in making crosses between types of cotton, the inheritance is largely of a simple Mendelian character though there are a number of qualities, which are either non-Mendelian or else of a more complex kind than that ordinarily found. Apart, therefore, from the wish to obtain improved types of cotton suitable for a particular tract, it seemed also of importance to ascertain how two varieties of cotton, in pure line, behaved with regard to some of these apparently complex characters. The progress made on these lines is the chief subject of the present memoir.

* See pages 85 and 106.

II. THE TYPE OF COTTON DEMANDED FOR THE KUMPTA AREA.

The interest of the whole question of cotton crossing for the author has lain on the fact that he has been long employed in the attempt to obtain improved types of cotton for the area which now grows the variety of *Gossypium herbaceum* known as *kumpta* cotton. Work has continued for many years on the lines of selection of the best and most suitable types for that area from the existing crop, and with considerable success. A full account of this work has been given in another memoir.¹ But it quickly became apparent that progress by this method here, as elsewhere, was limited, and further advancement towards the ideal type of cotton plant for this tract could obviously only be made by introducing the missing qualities in the best strains of the local cotton by crossing with other types.

The type of cotton which appears most suited to the Kumpta tract has been already described (*loc. cit.*). The essential points are a relatively rapid flowering and fruiting type of plant, and hence a plant which is, adopting Leake's classification, essentially sympodial. This has been secured by the isolation of a pure strain known as Dharwar No. I. This has the qualities of quick growth, of early flowering, and rapid fruiting which are needed in the Kumpta tract. On the other hand, it has the following disadvantages.

(1) Though the ginning percentage is high (28·5) as compared with that of most strains of *kumpta* (25·5), yet it is low compared with many other types of cotton grown in India, and even of many types of *herbaceum* cotton. Thus *broach* cotton, a *herbaceum* type grown in Gujarat, has normally a ginning percentage of 32, and some strains go considerably higher. The *neglectum* cottons nearly always approach a ginning percentage of 36 to 38 and so on.

It was obviously desirable that this faculty of high ginning should be introduced into the *kumpta* cotton if this can be done without loss of the yielding power and staple of Dharwar No. I.

(2) The colour of the *kumpta* cottons is always dull white with a tinge of red, and no selection has enabled this character to be overcome. Now the Gujarat *herbaceum* and the *neglectum* cottons generally are very white, and if this could be secured without losing the faculties which give *kumpta* its special value for the area in which it is grown, a much more valuable product both to the cultivators and to the market will be secured.

(3) The tall erect character of the plant should be emphasised in any cross that is made, or in other words the sympodial character of Dharwar

¹ Kottur. *Kumpta Cotton and its Improvement. Mem. Dept. Agri. Ind., Bot. Ser., Vol. X, No. 6 (1920).*

No. I should be emphasised in the cross, as this means earliness, an exceedingly important quality for the Kumpta tract.

Thus a type is to be secured by crossing which has all the good qualities of Dharwar No. I, and, in addition, has a considerably larger ginning percentage in the *kapas*, a better colour in the lint and a tendency to emphasise the earliness of the plant. To obtain these advantages easily there are only two Indian types with which it is obviously worth while crossing the Dharwar No. I strain of *kumpta*. These are (1) strains of high ginning Gujarat *herbaceum* cottons, of which possibly the *goghari* type is the most suitable, and (2) strains of *neglectum* cotton, chiefly from the high yielding, high ginning types from Berar or Khandesh. Between these two the decision is easy, for while the Gujarat *herbaceums* are desirable in other respects, they are all monopodial in character and hence bushy in growth and late in flowering and fruiting. The *neglectum* cottons, on the other hand, give equal ginning percentage, have an equally good colour, and are erect essentially sympodial plants.

It was hence decided to proceed with the crossing of the pure line of the *kumpta* variety of *Gossypium herbaceum* known as Dharwar No. I and a pure line of *Gossypium neglectum* isolated by the author from the narrow-lobed, white-flowered type of Sholapur cotton (which is essentially identical with that from Khandesh), and it is an account of this cross and its behaviour that forms the remainder of the present memoir.

III. THE PARENTS OF THE CROSS.

The parents of the proposed cross may first be described.

(1) The Dharwar No. I strain of *Gossypium herbaceum* was isolated by the author in 1913 from the *kumpta* cotton grown at Dharwar. It has been described in detail in the memoir previously referred to (pages 254-261) and this description therefore need not be again repeated. But its principal characters can be indicated as follows :—

- (a) The stalk of the cotyledons is green throughout, as is the case with all *herbaceum* cottons.
- (b) The number of monopodia on each plant varies from 0 to 5, with the mode at 3. 79·7 per cent. of the whole plants examined have either 2 or 3 monopodia per plant.
- (c) In leaf character, the plant may be shortly described as one with short and broad lobes, with a leaf factor—to use Leake's term—of about 1·4.
- (d) The flower is yellow, and the petals are from 22 to 39 millimeters in length, the mode standing at 28 to 30 millimeters.

- (e) Nectaries are present both on the leaves and on the bracteoles.
- (f) As already stated, the colour of the cotton is dull white with a tinge of red.
- (g) The ginning percentage varies from 26 to 29, with mode at 28. Only one per cent. of plants had a ginning percentage as high as 30.
- (h) The mean seed weight was 0.057 grammes, and was, as we shall see, almost identical with that of the other parent.
- (i) The staple of the lint ranged from 0.8 inch to 1.1 inch with a mode of 0.9 to 1.0 inch.

(2) The strain of *Gossypium neglectum* used for this cross has not been described before, and hence a somewhat detailed account must be given of such of its various characters as have importance for the present experiments. It belonged to the narrow-leaved, white-flowered variety of this species which has been called *Gossypium neglectum* var. *rosea* by Gammie.¹ This forms, as is well known, the most highly ginning element in the mixture commonly grown in the regions of India growing *neglectum* cottons. A picture of a typical plant is shown in Plate I.

The characters important for our present purpose are as follows :—

- (a) The stalk of the cotyledons is red at the tip, like all *neglectum* cottons, differing thus from Dharwar No. I with which it is to be crossed.
- (b) The number of monopodia on each plant varies from 0 to 3, the most frequent number being 2. The number of monopodia on 1,000 plants in 1919-20 was as follows :—

Number of monopodia	Frequency
0	11
1	191
2	598
3	200
4	0

It will be seen that the number of monopodia is rather less than on the Dharwar No. I strain with which it is crossed, though both of them would be classed as sympodial cottons.

(3) The leaf characters show extreme difference from that of the other parent of the cross, previously described, and the leaves would be described as long and narrow-lobed, with a leaf factor of 3.5. Exactly what this means

¹ Gammie. The Indian Cottons. Mem. Dept. Agri. Ind., Bot. Ser., Vol. II, No. 2 (1907).



Fig. 1. Parents of the cross.



is shown by the figures of typical leaves of this strain shown in Fig. 1. They are all primary leaves, and represent either the 5th, 6th, 7th or 8th formed

	BREADTH (mm.)									
	13	16	19	22	25	28	31	34	37	40
LENGTH (mm.)	15	18	21	24	27	30	33	36	39	42
37-39					6	13	DHARWAR I			
40-42						58	44			
43-45					5	61	74	19		
46-48		ROSEA				31	81	69	5	4
49-51	3						11	6	3	4
52-54	5	9	10					2	1	1
55-57	25	13	6							
58-60	20	48								
61-63	35	34								
64-66	35	30	20							
67-69	5	35	5							
70-72		58	13							
73-75		18	17							
76-78			8							

FIG. 1.

on the main stem of the plant. As there is considerable variation in the leaves in different parts of the plant and between large leaves and small, the above mentioned leaves have been kept throughout for all our measurements.

Taking these leaves, and measuring the length and breadth of the middle lobe of the leaf on many plants, the contrast between the character in the *Gossypium neglectum (rosea)* under discussion is well shown in the following correlation table. It will be seen that all the leaves of Dharwar No. I have a lobe with no greater length than 52 mm., while none of the *rosea* type are shorter than 51 mm. Likewise the middle lobe of the whole of the leaves of Dharwar No. I type has a breadth exceeding 25 mm., while all those of the *rosea* type are under 21 mm. Generally speaking, the following table shows

the limits in the two cases, in a large number of plants grown close together at Dharwar.

Name of cotton			Length of middle lobe	Breadth of middle lobe
			mm.	mm.
Dharwar No. I	..	..	37 to 52	25 to 42
Rosea	..	..	51 to 78	13 to 21

The relationship between the length and breadth of the lobe is almost exactly Leake's leaf-factor, and we will discuss the importance of this later on.

(4) The characters of the flower are equally contrasted in the two parents. Thus the colour of the flower in the strain of *Gossypium neglectum*, which has been used as parent, is almost pure white, and thus contrasts at once with the bright yellow corolla of Dharwar No. I. The length of the petals is also characteristic, they being much shorter than in the case of the other parent. The modal value for the length of the petal lies between 16 and 21 mm. and very few (not more than 8.2 per cent.) are over 21 mm. This contrasts clearly with the measurements for Dharwar No. I where the modal value for the length of the petal lies between 25 and 30 mm. and only 1.2 per cent. are less than 22 mm.

A peculiarity of the flowers of this strain of *Gossypium neglectum* is the fact that at Dharwar in November, December and January the flowers do not open. In the latter part of January and in February they open late in the day (about midday) and remain open a very short time. These late flowers are of little consequence because they are shed almost entirely, and, hence, we have in this strain one whose seed is almost all produced from cleistogamic flowers and is hence naturally self-fertilized.

(5) Both foliar and extra floral glands are altogether absent in the strain of *Gossypium neglectum* which we have used.

(6) The colour of the lint, as is usual in *neglectum* cottons, is pure white.

(7) The ginning percentage of the *kapas* is an exceedingly important matter, and in the present strain of *Gossypium neglectum* it varied from 30 to 40, with a mode between 35 and 38. The actual proportion of plants with each ginning percentage is as follows, obtained from an examination of 100 plants.

Ginning percentage	Frequency
30	2
31	0
32	1
33	4
34	8
35	12

Ginning percentage	Frequency
36	30
37	28
38	11
39	2
40	2

This contrasts markedly with Dharwar No. I where the ginning percentage is as high as 30 in only one plant out of a hundred, the rest varying from 26 to 29. The range in each case hardly overlaps the other.

(8) The seed weight is practically identical with that of Dharwar No. I. The shape is rather different, that in *rosea* being round with no depressions on the surface such as are found with the seeds of the *herbaceum* parent.

(9) The staple in the *Gossypium neglectum* parent is confessedly short, and the fibre from the middle of the seed never exceeds 0.7 inch in length, while it is generally 0.6 inch or below.

It will be noticed that the range of variation in some of the characters of this strain of *Gossypium neglectum* is somewhat larger than might be expected in a pure line, and hence it became important to ascertain how far, for one at least of the factors which are really important, it might be considered as hereditarily pure. The best way of getting this information appeared to be that of taking seed produced by individuals from near the two extremes of variation, and growing them. The variation of characters in the progeny should be very closely similar to that occurring in the parent. This variation has been worked out in this manner in 1921-22 for the ginning percentage of the *kapas* which was, for the author, the most important character, and the plants obtained gave the following frequency distribution :—

Ginning percentage	Frequency of ginning percentage			
	Parent	I Progeny of plant with 33 ginning percentage	II Progeny of plant with 36 ginning percentage	III Progeny of plant with 39 ginning percentage
30	0	3	2	3
31	5	2	1	4
32	10	9	7	13
33	14	21	18	21
34	29	34	25	26
35	40	45	49	47
36	64	57	59	60
37	56	60	64	38
38	25	15	16	29
39	7	1	5	6
40	0	3	4	3
	250	250	250	250

These figures indicate that there is an almost exactly similar distribution of the frequency of various ginning percentages in the progeny for plants of varying ginning percentages. It may be taken, therefore, that in ginning characters we have in the *Gossypium neglectum* (rosea) type used for crossing, a pure line in this variety. (Fig. 2.)

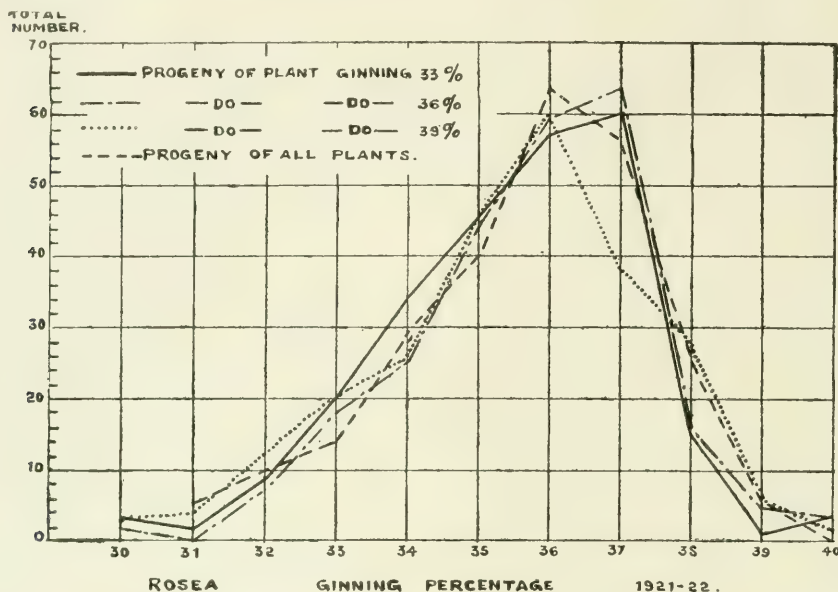


FIG. 2.

Taking all together, therefore, we have two parents which are very similar as to the general character of the plant, and as to the seed weight. They are, on the other hand, markedly contrasted as to (1) the colour of the stalk, (2) the shape of the leaf, (3) the colour of the flower and the length of the petal, (4) the presence of nectaries both foliar and extra floral, (5) the colour of the lint, (6) the ginning percentage of the *kapas*, and (7) the staple of the lint. The following table shows these characteristic differences, which had (previous to the crosses being made) been shown to be constant within known limits, under self-fertilization, during several seasons :—

			<i>Gossypium herbaceum</i> Dharwar No. I	<i>Gossypium neglectum</i> <i>rosea</i>
(1) Colour of the stalk	..	..	Wholly green	Red at the tip
(2) Shape of leaf	..	..	Short and broad-lobed. Leaf factor 1.7	Long and narrow-lobed. Leaf factor 3.7
(3) Colour of flower	..	..	Bright yellow	White

				<i>Gossypium herbaceum</i> Dharwar No. I	<i>Gossypium neglectum</i> <i>rosea</i>
(4) Nectaries	..	..	..	Present	Absent
(5) Colour of lint	..	..	..	Dull white with reddish tinge	Pure white
(6) Ginning percentage of <i>kapas</i>		..	..	26 to 30 (mode 27 to 29)	30 to 40 (mode 35 to 38)
(7) Staple of lint	..	..	..	0.8 to 1.1 inch	0.4 to 0.7 inch

It is to the behaviour of the cross between these two types of cotton, in these contrasted characters, that the principal attention of the author has been directed.

IV. THE METHOD OF MAKING THE CROSS.

Cotton is normally a self-fertilized plant, but it is now proved that a certain limited amount of crossing does take place when different strains or varieties of cotton are grown in close proximity. This depends very largely on the number of insects present and particularly on the number of bees. At Dharwar the author's experiments would indicate that, with the strains with which he has worked, about two per cent. of natural crossing is normal, and this being the case, it is obvious that in all critical work the flowers must be protected from such natural crossing.

The method first adopted was to protect the flower buds with paper bags. This method has been frequently used in India and probably elsewhere. It has, however, been much criticised. Balls¹ objected to it in Egypt as it caused a great deal of shedding of flower buds and flowers. Leake² protected many thousands of flowers with paper bags, but found that his method led to a considerable degree of sterility. The author's experience of the methods under discussion was that the paper bags were very troublesome to use, and not very effective in a windy area, as they are liable to be torn and hence their value destroyed. The method has been abandoned in Madras, and a system of sewing up the flowers adopted in its place.³ The author now only uses the paper bag method in protecting the flowers of the pollen parents and the buds operated upon in actual artificial crossing. In this case no satisfactory substitute has been found.

¹ *Cotton Plant in Egypt*, p. 117.

² *Jour. Genetics*, Vol. I., p. 207.

³ *Ann. Report. Dept. of Agri., Madras* (1913).

In all other cases, where self-fertilization is desired, and hence complete protection from any chance of the admission of foreign pollen, the author has adopted a method of keeping the flowers closed by means of small wire rings.¹ The method was described in 1919, and has given satisfactory results, both before and since that time. The method is illustrated in the sketch below (Fig. 3) and consists of putting the small rings on to the fully developed

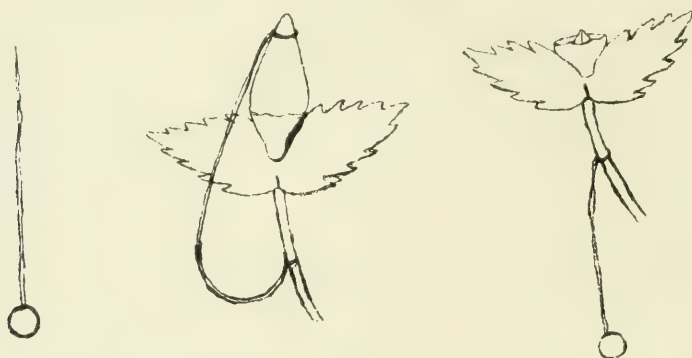


FIG. 3.

buds before they commence opening. The form of the flower being a cone, there is no difficulty in putting the rings tight, and so completely preventing the opening of the petals. The stalk of the protected flower is marked by a piece of cotton thread attached to the ring. In almost all cases, there is no further trouble. Occasionally, however, the ring slips off and the buds are thus allowed to open. All such flowers are removed, however, as soon as found.

The method thus described has been used with all the plants in which self-fertilization is essential, and all the results described in the present paper have been obtained with flowers so protected.

V. THE CHARACTERS OF THE HYBRID PLANTS.

The cross between the pure strains of *Gossypium herbaceum* and *Gossypium neglectum* var. *rosea* already described was made in December 1917, and twenty-two bolls were obtained which were sown separately in August 1918 (F₁). All gave plants and produce of one type, and it was evident that the cross had been successful in all cases. Among the plants grown, twelve were protected from cross-fertilization and self-fertilized and these yielded the

¹ *Agri. Jour., India*, Vol. XIV, p. 177.

material for the next generation's cultivation. The seed from each of these plants was grown separately, and it was at once obvious that much splitting of characters was taking place. Careful study of this was made, and the seed from plants of this generation (F_2) which showed any promise, and which were again protected from cross-fertilization, was again sown in 1920, the result being again carefully examined in the F_3 generation. A similar study was made of the F_4 generation sown in 1921. In the present chapter of this memoir, the author wishes to follow, through these four generations (F_1 , F_2 , F_3 , F_4) of the cross, the behaviour of the characters already indicated.

(A) COLOUR OF THE COTYLEDONARY STALK.

This character, which has of course only a scientific interest, was only followed through the F_1 and F_2 generations, as the climatic conditions in 1920-21 were unfavourable to obtaining correct results. Starting from the green stalk of Dharwar No. I and the deep red stalk of the *neglectum* parent (*rosea*), it was found that the F_1 generation gave a stalk which was *faint* red in every case. In the F_2 generation, there was a splitting of types resulting in coloured stalks as follows:—

Total number of plants examined	..	..	1,263
Deep red stalks ..	..	..	132
Faint red stalks ..	..	..	930
Green stalks ..	..	..	201

This gives a proportion between the different types of stalks of 1 : 7 : 1.5.

It is quite unsafe to suggest any reason for this proportion, on the basis of the two generations considered. It is obvious, however, that the colour is not a simple Mendelian character, involving the presence or absence of one colour factor.

(B) SHAPE OF LEAF.

The question as to the result of the cross between the two cotton types described in the matter of the shape of the leaf is of very great—though chiefly of theoretical—interest. The matter of how their character is inherited has already been discussed by Leake¹ on the basis of a cross between *Gossypium arboreum* and *Gossypium neglectum*. He has devised a co-efficient, which he terms the “leaf-factor,” to represent the shape of the leaf. This leaf-factor is composed by subtracting the distance from the petiole to the sinus (l_1) from the length of the leaf from the petiole to the

¹ *Jour. Genetics*, Vol. I, No. 3, p. 224 (1911),

tip of the middle lobe (1), and dividing by the maximum breadth of the middle lobe (b). It is thus :

$$\frac{1-1_1}{b}$$

Though he finds that this factor varies somewhat with different leaves on the same plant, he considers that it is quite easy to select typical leaves, and his results for any plant are always based on the average figures given by two such leaves. A typical leaf was taken as being one which represented "the average of the factors of all leaves arising from the monopodial branches."¹

He considers this factor as a single constant character, and that blending between the qualities represented by a long narrow-lobed leaf and a short broad-lobed leaf may occur in any proportion. A consideration of his results, however, does not definitely prove that the leaf-factor is really single inheritable quality, and some of them suggest that it may be a combination of two factors varying independently. The results which the author has obtained seem calculated to throw some light on the very obscure question of the inheritance of these leaf characters and they may therefore be discussed in some detail.

Instead of the "leaf-factor" as defined by Leake, the almost identical figure obtained by dividing the measurement of the length (1) and the breadth (b) of the middle lobe of the leaf has been used. This is simpler to obtain and varies so little from the figure given by Leake that it may be used without appreciable error. To exclude chance variations in a single plant, the measurements for each plant in a type were always made on either the fifth, sixth or seventh leaf arising on the main stem, when it was fully developed.

But while the leaf-factor has been used, the elements of which it is composed, the length and the breadth of the middle lobe have themselves been considered as possible hereditary characters, and their values in the parents and the offspring have been compared down to the F₄ generation. The difficulty in this case is that the absolute length and breadth of the middle lobe of the leaf are dependent not only on the innate hereditary characters of the plant itself, but also on the vigour with which the particular plant measured is growing. This difficulty is not altogether absent from the use of the leaf-factor itself, for when a plant is specially vigorous the middle lobe of the leaf increases in length faster in proportion to the increase in breadth.

This is clearly indicated by the following figures obtained from vigorous and non-vigorous plants of the same pure line of *Gossypium herbaceum* and also of *Gossypium neglectum* (rosea). (Fig. 4.)

¹ *Loc. cit.*, p. 229.

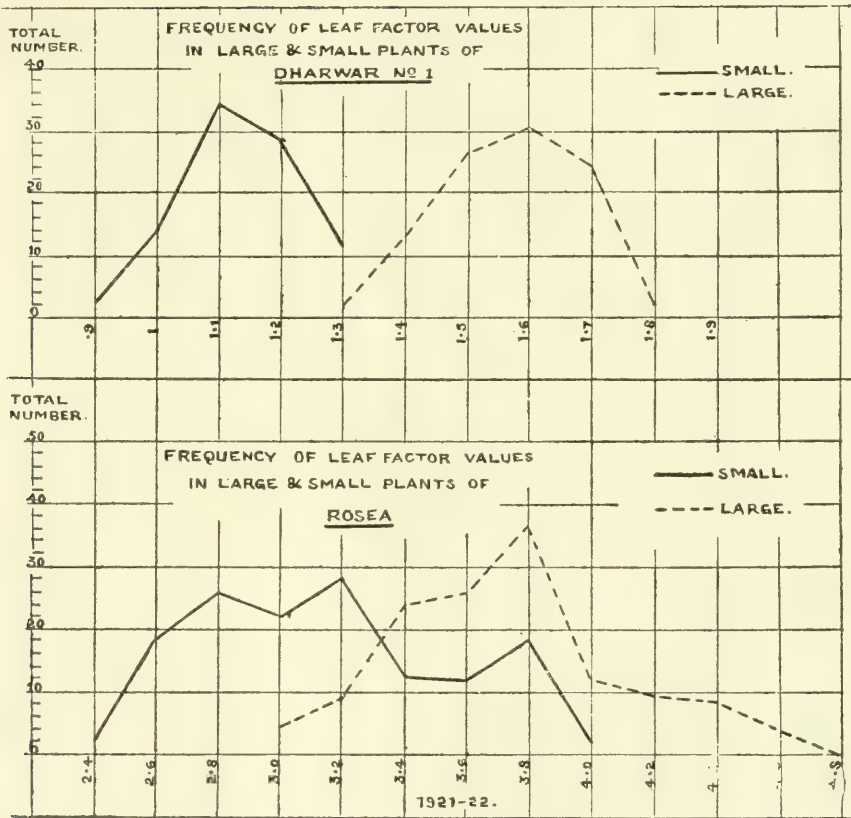


FIG. 4.

Gossypium herbaceum (Dharwar No. I)

Leaf-factor and frequency.

(From 100 plants.)

Factor				Large plants	Small plants
0.9	..	..	..	..	2
1.0	..	..	..	..	16
1.1	..	..	..	..	38
1.2	..	..	..	..	31
1.3	..	..	..	2	13
1.4	..	..	..	13	..
1.5	..	..	..	27	..
1.6	..	..	..	32	..
1.7	..	..	..	24	..
1.8	..	..	..	2	..
				100	100

GOSSYPIMUM NEGLECTUM (ROSEA)

Leaf-factor and frequency.

(From 138 plants.)

Factor				Large plants	Small plants
2.4-2.5	..	..	..	..	6
2.6-2.7	..	..	..	..	23
2.8-2.9	..	..	..	1	22
3.0-3.1	..	..	..	9	39
3.2-3.3	..	..	..	10	21
3.4-3.5	..	..	..	32	8
3.6-3.7	..	..	..	48	12
3.8-3.9	..	..	..	2	6
4.0-4.1	..	..	..	20	1
4.2-4.3	..	..	..	11	..
4.4-4.5	..	..	..	1	..
4.6-4.7	..	..	..	4	..
				138	138

So that it seems clear that the ratio which forms the leaf-factor itself is by no means constant, but tends to increase with the vigour of the plant.

Let us, however, first examine the constancy of the leaf-factor (1) on the same plant, (2) on plants of one pure strain. Leake states that this constancy with the strains he studied is very great, and that in the broad-lobed types (*i.e.*, those possessing a leaf-factor less than 2), the variation from the mean on one plant does not exceed 0.15 or a total range of 0.3. In the narrow-lobed types (*i.e.*, those with a leaf-factor greater than 3) the variation is greater, amounting to 0.3 from the mean, or a total range of 0.6¹. The author's figures do not bear this out in every case. With the broad-lobed types, however, the constancy is fairly great, and the variation on one plant of Dharwar No. I has never exceeded 0.28, these figures being obtained from measurements of primary leaves from 500 plants. The range of variation obtained in different plants of the strain grown in one year is shown by the following measurements made on 508 plants, the leaves always used being the fifth, sixth, and seventh on the main stem.

Leaf-factor				Frequency	Per cent.
1.1-1.29	..	..	..	13	2.6
1.3-1.49	..	..	..	288	56.7
1.5-1.69	..	..	..	190	37.3
1.7-1.89	..	..	..	17	3.4

¹ *Loc. cit.*, p. 223.

The range between the extremes in this case among all plants of this strain is 0·7 or rather more than double what Leake found from his single plants of broad-lobed varieties.

When we consider the narrow-lobed varieties, the constancy of the leaf-factor, on which Leake lays great stress, no longer exists and the primary leaves *on a single plant* show themselves to be extremely variable. Thus in two single plants of the strain of *Gossypium neglectum* var. *rosea* used for the cross in 1920-21 the following variations were found, using only fully developed leaves on the main stem.

Leaf-factor.

Number of leaf (from base)				Plant No. I	Plant No. II
5th	..	..	..	3·1	3·1
6th	..	..	..	3·5	3·1
7th	..	..	..	3·5	3·0
8th	..	..	..	4·5	3·7
9th	..	..	..	3·9	3·9
10th	..	..	..	4·1	4·1
11th	..	..	..	4·4	4·0
12th	..	..	..	4·0	3·8
13th	..	..	..	3·9	4·0
14th	..	..	..	3·8	4·1
15th	..	..	..	3·8	4·3
16th	..	..	..	3·5	4·0
17th	..	..	..	3·5	3·8
18th	..	..	..	4·1	3·6
19th	..	..	..	4·0	3·8
20th	..	..	..	3·4	3·7
21st	..	..	..	3·5	3·1
22nd	..	..	..	4·1	3·2
23rd	..	..	..	4·1	3·6
24th	..	..	..	..	..
25th	..	..	..	..	..
Mode				3·5	3·1, 3·8, and 4·0
Mean				3·8	3·7
Range				1·4	1·3

Range as percentage of mean value. 36·8 per cent. 35·1 per cent.

It is obvious here that the variation on one and the same plant are of a totally different order from those indicated in Leake's figures. Though, if the measurements are limited to the leaves we have taken (5th, 6th, and 7th) for our general measurements, the range is much reduced, yet the fact that if we take say the 13th or the 15th leaf we should have got very wide difference from the finally recorded mean, rather tends to destroy our confidence in the factor itself. Leake¹ confesses that the leaf-factor is a purely empirical figure, and it became essential to find the reason for this very wide variation of mature primary leaves on a single plant.

Before indicating what this is we may, however, consider the figures obtained if we take not single plants but the strain as a whole. The factor was determined in fact on 594 plants of this strain growing at the same place at the same time (in 1920-21), the 5th, 6th, and 7th leaves being used in every case for measurement. The results are as follows:—

Leaf-factor				Frequency	Percentage
2.3-2.4	..	..	..	5	0.8
2.5-2.6	..	..	..	14	2.3
2.7-2.8	..	..	..	40	6.7
2.9-3.0	..	..	..	52	8.7
3.1-3.2	..	..	..	82	13.9
3.3-3.4	..	..	..	78	13.0
3.5-3.6	..	..	..	83	13.9
3.7-3.8	..	..	..	42	7.0
3.9-4.0	..	..	..	68	11.6
4.1-4.2	..	..	..	39	6.7
4.3-4.4	..	..	..	56	9.5
4.5-4.6	..	..	..	11	1.9
4.7-4.8	..	..	..	7	1.1
4.9-5.0	..	..	..	13	2.2
5.0-5.2	..	..	..	4	0.6
Mode				3.1 to 3.6	
Mean				3.5	
Range				2.8	
Range as percentage of mean value 80.0 per cent.					

Now, while the range in this case is higher than with a single plant, yet it is not more variable than would have been expected, having regard to the range of variations in leaves similarly placed on different single plants (see above: 3th leaf 0.8, 15th leaf 0.5, 16th leaf 0.5), and it compels a further analysis into the cause of the variation. Is this variation due, in fact, (a) to variability in the type, (b) to variability in one of the elements which make up the

¹ *Loc. cit.*, p. 225.

leaf-factor, or (c) to variability in both of the elements which make up the leaf-factor ?

The variability cannot be due to more than a minor extent to that of the type, because (as shown above) the variation in a single plant is, though smaller, of the same order as that in the whole series of 596 plants. But let us consider the variation in the elements which make up the leaf-factor (a) in single plants, and (b) in the whole strain.

Taking the same plants as those for which the leaf-factor was given above we have for the mature leaves on the main stem from the 5th upwards as follows.

Length and breadth of middle leaf lobe.

			PLANT NO. I		PLANT NO. II	
Leaf number			Length of middle lobe	Breadth of middle lobe	Length of middle lobe	Breadth of middle lobe
			mm.	mm.	mm.	mm.
5th	..	..	75	24	75	24
6th	..	..	75	21	75	24
7th	..	..	78	27	90	30
8th	..	..	96	21	99	27
9th	..	..	93	24	105	27
10th	..	..	99	24	99	24
11th	..	..	105	24	96	24
12th	..	..	96	24	102	27
13th	..	..	93	24	96	24
14th	..	..	81	21	99	24
15th	..	..	81	21	90	21
16th	..	..	75	21	96	24
17th	..	..	75	21	81	21
18th	..	..	75	18	75	21
19th	..	..	72	18	81	21
20th	..	..	78	21	78	21
21st	..	..	75	21	75	24
22nd	..	..	75	18	78	24
23rd	..	..	..	..	75	21
Mode	..	..	75	21	75	24
Mean	..	..	82.9	21.3	87.6	23.9
Range	..	..	33	6	30	9
Range as percentage of mean			39.8 per cent. 28.2 per cent. 34.2 per cent. 37.7 per cent.			

From this it would appear that the variation in each of these elements, the length and the breadth of the middle lobe, is about equal, in the same plant, to that of the leaf-factor itself. We may now see what is the case

with a whole population of 600 plants grown in the same year as the above. This has worked out as follows :—

Length of middle lobe	Frequency	Breadth of middle lobe	Frequency
mm.		mm.	
63	21	18	42
66	24	21	240
69	26	24	188
72	36	27	96
75	116	30	34
78	51	..	..
81	54	..	..
84	46	..	..
87	35	..	..
90	62	..	..
93	45	..	..
96	21	..	..
99	18	..	..
102	17	..	..
105	17	..	..
108	8	..	..
111	3	..	..
Mode	.. 75 and 90		21
Mean	.. 82.1		23.2
Range	.. 48		12
Range as percentage of mean value	58.4 per cent.		57.7 per cent.

These figures show that while the range of variation of the leaf-factor in a single plant is practically as great as that of the actual measurements of length and breadth of the middle lobe of the leaf, its variability in a large population grown side by side in the same year is much greater (nearly double) than that of the actual measurements. This being the case, it would appear that the use of the leaf-factor tends to magnify the variability in this type of cotton and that considerably more constancy would be obtained by taking the actual measurements of specified leaves of plants grown side by side in the

same year, than by taking the combined co-efficient which Leake has termed the "leaf-factor."

In addition to this, it may be noted that though the co-efficient of variability of both the length and breadth is nearly the same, being 13.15 as regards the length (standard deviation 10.8 mm.) and 12.41 as regards the breadth (standard deviation 2.88 mm.), yet there is only very small correlation between the length and breadth. In other words, the length and breadth do not necessarily increase together, the co-efficient of correlation being only 0.28. This being the case, there seems strong reason for rejecting the leaf-factor, as a single unit, in the studies of the results of crossing, because

- (1) The leaf-factor is more variable than the elements (length and breadth of the middle lobe) of which it is composed.
- (2) The correlation between these elements is only slight.

We will, therefore, consider these elements as separate units, always providing (1) that the plants whose leaf characters are to be compared must be grown in the same year, at the same place, and at the same time, (2) that the leaves taken for measurement be always in a similar position on the plant. The author has always used the fifth, sixth or seventh leaf arising on the main stem as the basis for his measurements.

The characters of the middle lobe of the leaves, selected as just indicated, in the case of the parents of the cross, of the F_1 generation and of the F_2 generation, were determined on plants grown side by side in 1919-20 and the general results so far as the parents and the F_1 generation are concerned are graphically shown in Fig. 5. It will be seen from this that the length of the middle lobe in the two parents is as follows :—

Dharwar No. 1	..	..	37 to 54 mm.
<i>Rosea</i>	..	..	49 to 78 mm.

These figures hardly overlap. In fact, if we take a length of 51 millimeters as the line between them, only 4 out of 500 or 0.8 per cent. of the Dharwar No. 1 plants are above this line and only 3 out of 538 or 0.55 per cent. of the *rosea* type are below this line. In fact, we may take it that the range of variation in the two cases is separate, and that for practical purposes there is no overlapping of the types in this particular.

In the breadth of the middle lobe, the range of variation is, again, quite independent. The whole of the Dharwar No. 1 leaves have a breadth greater than 25 millimeters and the whole of the *rosea* leaves have a breadth less than 20 millimeters.

The behaviour in the F_1 generation is striking. All the plants obtained had figures for the dimensions of the middle lobe of the cross which indicated

a leaf of the type of *rosea* as to the length of the lobe, and of the type of Dharwar No. I as to the breadth of the lobe. This is shown by the following figures. (Fig. 5.)

		BREADTH (mm.)											
		13	16	19	22	25	28	31	34	37	40		
		15	18	21	24	27	30	33	36	39	42		
LENGTH (mm.)	37-39					6	13	DHARWAR 1					
	40-42						58	44					
	43-45					5	61	74	19				
	46-48	ROSEA					31	81	69	5	4		
	49-51	3						11	6	5	4		
	52-54	5	9	10	1	5	1		2	1	1		
	55-57	25	13	6		F!	1						
	58-60	20	48		1	3	2	5					
	61-63	35	44			1							
	64-66	35	90	20	7		8	6	5				
67-69	5	35	5			4	2						
70-72	16	58	13			6	5	1					
73-75		18	17		1	1	1						
76-78			8			1	3	6	2	2			
79-81								1					
82-84						3		6	3	2			
85-87										1			
88-90								2	1				

FIG. 5.

Name of cotton		Length of middle lobe	Breadth of middle lobe
		mm.	mm.
Dharwar No. I	..	37-54	25-42
<i>Rosea</i>	..	49-78	13-21
F ₁	..	52-90	22-42

It will be noted, however, that in the F₁ generation the length tends, in the extreme cases, to be higher than any examples found among the parents. This tendency has already been noted by Leake.¹

¹ *Loc. cit.*

From a consideration of these figures, tables, and curves, it would be natural to suspect practically complete dominance of the long leaf lobe over the short one, and of the broad leaf lobe over the narrow one, giving a leaf in the F_1 generation with a long-broad middle lobe. The actual characters of the leaf in the parents and in the F_1 generation are shown in Plate II.

Exactly what this apparent dominance means is elucidated by a study of the F_2 generation where 837 plants were grown and gave results shown in the following frequency tables, being worked out to a basis of 500 plants in each case.

Length of middle lobe.

Length			Dharwar No. 1	<i>Rosea</i>	F_1	F_2
mm.						
28-30	..	..	..	..	..	1
31-33	..	..	..	..	..	..
34-36	..	..	..	..	..	12
37-39	..	..	18	..	..	5
40-42	..	..	102	..	..	20
43-45	..	..	160	..	..	23
46-48	..	..	190	..	..	46
49-51	..	..	26	3	..	31
52-54	..	..	4	24	35	61
55-57	..	..	..	44	5	19
58-60	..	..	..	58	55	65
61-63	..	..	..	79	5	52
64-66	..	..	..	145	130	62
67-69	..	..	..	45	30	29
70-72	..	..	..	59	60	42
73-75	..	..	..	35	15	11
76-78	..	..	..	8	70	16
79-81	..	..	..	..	5	1
82-84	..	..	..	..	70	7
85-87	..	..	..	..	5	1
88-90	..	..	..	..	15	3
91-93	..	..	..	..	..	2
94-96	..	..	..	..	..	1

Breadth of middle lobe.

Breadth			Dharwar No. I	<i>Rosea</i>	F_1	F_2
mm.						
10-12	..	..	..	..	..	2
13-15	..	..	..	134	..	26
16-18	..	..	..	287	..	51
19-21	..	..	..	79	..	55
22-24	..	..	..	..	45	104
25-27	..	..	11	..	50	116
28-30	..	..	163	..	135	68
31-33	..	..	210	..	120	41
34-36	..	..	96	..	100	26
37-39	..	..	11	..	30	9
40-42	..	..	9	..	20	1
43-45	..	..	..	..	..	1

Taking the question of lobe *length* first, and taking a length of 51 mm. as separating long lobes from short ones, it is found that in the F_1 generation all the plants have leaves which would be classed as long* and in the F_2 generation the proportion is as follows (out of 837 plants).

			Total	Proportion
Long-lobed leaves	..	..	605	2.61
Short-lobed leaves	..	..	232	1

The proportion, in fact, approaches what one would expect to get with a single pair of hereditary characters.

With the leaf breadth the position is similar. A width of 21 mm. may be taken to divide narrow from wide leaves, as *all* the *narrow* types are below this limit, and all the broad types above it. In the F_1 generation all the plants have leaves conforming to this definition of a broad-lobed leaf, and in the F_2 generation the figures are as follows (out of 837 plants).

			Total	Proportion
Broad-lobed leaves	..	..	611	2.7
Narrow-lobed leaves	..	..	226	1

The result is, in fact, exactly similar to that obtained above in studying the length of the lobe, that is to say, the proportion is very nearly what would be expected with a simple pair of hereditary characters.

If these two lobe characters are studied together, and they are considered as two pairs of hereditary characters, varying independently, we get the following results in the F_2 generation out of 837 plants.

Characters of leaf lobe		Total	Proportion
Long broad	..	431	8.3
Long narrow	..	174	3.3
Short broad	..	180	3.4
Short narrow	..	52	1

This is very nearly the proportion which would be expected (9 : 3 : 3 : 1) if two simple characters were varying independently, and it was clear that a study of the next generation of plants (F_3) would confirm or otherwise the truth of this deduction.

The study of the third generation (F_3) was made in 1920-21, and as the plants were now grown in a new year it became necessary to remeasure the length and breadth of the lobes of parents, F_1 and F_2 , along with the F_3 generation, in order to see whether, under the conditions of the new season, the

* This is justified, as all one parent (except 0.8 per cent.) are below this limit and all the other parent (except 0.6 per cent.) are above it. It is in no sense an artificial point.

same standards of length and breadth could be taken as before. The results obtained were as follows :—

Length of middle lobe.

Length	Dharwar No. I	Rosea	F ₁
mm.			
28-30	8	..	..
31-33	10	..	..
34-36	24	..	..
37-39	26	..	..
40-42	28	..	..
43-45	42	..	..
46-48	50	..	..
49-51	98	..	..
52-54	61	1	..
55-57	56	..	..
58-60	49	..	..
61-63	33	2	..
64-66	15	4	..
67-69	..	4	..
70-72	..	16	..
73-75	..	42	..
76-78	..	32	..
79-81	..	37	4
82-84	..	46	7
85-87	..	50	12
88-90	..	78	35
91-93	..	55	79
94-96	..	43	120
97-99	..	28	74
100-102	..	19	48
103-105	..	21	34
106-108	..	5	12
109-111	..	4	35
112-114	..	6	14
115-117	..	2	8
118-120	..	7	13
121-123	..	..	5

Breadth of middle lobe.

Breadth	Dharwar No. I	Rosea	F ₁
mm.			
16-18	..	47	..
19-21	..	152	..
22-24	..	191	..
25-27	..	82	..
28-30	4	28	..
31-33	62	..	..
34-36	76	..	31
37-39	141	..	97
40-42	123	..	131
43-45	52	..	128
46-48	36	..	91
49-51	6	..	22

The first thing to be noticed about these figures is the extreme importance and even necessity of growing all plants which are to be compared in the same year. The conclusions which were reached for a consideration of the 1919-20 figures are equally true here, but the leaves here are longer and broader, or, in other words, bigger than in the previous year. The length of the middle lobe of the two parents was—

Dharwar No. I	..	..	..	28 to 66 mm.
<i>Rosea</i>	..	..	..	61 to 120 mm.

These figures again hardly overlap. In fact if we take a length of 66 mm. as the line between the short and long leaves, no plants of the Dharwar No. I parent will be above this line, and only 6 out of 500 plants or 1·2 per cent. of the *rosea* parent are below it. The range of variation in the two cases is practically separate. The breadth of the middle lobe gives similar results. The range was as follows:—

Dharwar No. I	..	..	..	28 to 51 mm.
<i>Rosea</i>	..	..	..	15 to 30 mm.

Here we can take 30 mm. breadth as the dividing line, and if we do so, then only 4 plants (or 0·8 per cent.) of the Dharwar No. I parent overlap the range of the other type, while none of the *rosea* parent overlaps at all.

In the F_1 generation the results are similar to those recorded in the previous year. Both long leaf lobes and broad leaf lobes again appear as simple dominants and the conclusions already drawn (page 93) seem to be confirmed. The interest of the culture in 1920-21 lay, however, in the characters of the F_3 generation. For this the whole of the seed obtained from a certain number of each type of plant in the F_2 generation was used. The number so used was as follows:—

- (a) Seed from thirteen plants with long broad-lobed leaves.
- (b) Seed from seven plants with long narrow-lobed leaves.
- (c) Seed from five plants with short broad-lobed leaves.
- (d) Seed from one plant with short narrow-lobed leaves.

The results of growing these are shown in the following series.

(a) *From thirteen plants with long broad-lobed leaves.*

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	92	66	26	..	..	2.5	1.0	..	..
2 ..	102	76	26	..	..	2.9	1.0	..	..
3 ..	95	52	21	16	6	10.4	4.2	3.2	1.0
4 ..	71	39	16	11	5	8.0	3.2	2.2	1.0
5 ..	76	55	1	18	2	3.0	..	1.0	..
6 ..	93	93	..	..	..	1.0	..	..	..
7 ..	100	58	14	22	6	9.6	2.3	3.6	..
8 ..	60	32	14	11	3	10.6	4.6	3.3	1.0
9 ..	101	100	..	1	..	1.0	..	..	..
10 ..	83	61	20	2	..	3.0	1.0	..	..
11 ..	111	82	29	..	..	2.8	1.0	..	..
12 ..	118	86	3	29	..	3.0	..	1.0	..
13 ..	83	82	1	..	..	1.0	..	..	..

In this case, therefore, out of thirteen plants grown,

- (a) three were pure long broad-lobed leaf types ;
- (b) four were pure long-lobed types, but contained elements of both broadness and shortness. There is, on the average, a proportion of long broad-lobed types to long narrow-lobed types of 2.8 : 1. The proportion expected with one pair of varying characters would be 3 : 1 ;
- (c) two were pure broad-lobed types, but contained elements of both length and shortness. There is, on the average, a proportion of long broad-lobed types to short broad-lobed types of 3 : 1. This is exactly what would be anticipated ;
- (d) four contained elements of both length and shortness, and of breadth and narrowness. There is on the average a proportion of long-broad, long-narrow, short-broad, and short-narrow of 9.6 : 3.2 : 3.0 : 1.

The behaviour of the plants which had long and broad-lobed leaves in the F_2 generation was almost exactly what would have been expected on the hypothesis of two independently varying hereditary pairs of characters.

(b) *From seven plants with long narrow-lobed leaves.*

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	64	..	64	..	..	..	1.0	..	..
2 ..	88	..	69	..	19	..	3.6	..	1.0
3 ..	82	1	81	..	..	..	1.0	..	..
4 ..	87	3	60	..	24	..	2.5	..	1.0
5 ..	96	1	92	..	3	..	1.0	..	..
6 ..	82	1	80	..	1	..	1.0	..	..
7 ..	83	1	80	..	2	..	1.0	..	..

In this case, therefore, out of seven plants grown, five were, to all intents, pure long narrow-lobed types. The other two were pure narrow-lobed types, but contained elements of both length and shortness. There is, on the average, a proportion of long narrow-lobed to short narrow-lobed types of 3.1 : 1. This is almost exactly what would have been anticipated on the supposition of two independently varying hereditary pairs of qualities.

(c) *From five plants with short broad-lobed leaves.*

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	104	1	..	75	28	..	..	2.7	1.0
2 ..	95	1	..	63	31	..	..	2.0	1.0
3 ..	84	1	..	81	2	..	..	1.0	..
4 ..	47	..	..	46	1	..	..	1.0	..
5 ..	92	2	1	89	..	..	..	1.0	..

In this case, therefore, out of five plants grown, three were, to all intents and purposes, pure short and broad-lobed types. The other two were pure short-lobed types, but contained elements of both breadth and narrowness. There is, on the average, a proportion of short broad-lobed to short narrow-lobed types of 2.3 : 1. This is not quite the proportion expected (3 : 1) but considering the small number of plants investigated, it is not much further from it than perhaps might have been anticipated.

(d) *From one plant with short narrow-lobed leaves.*

Seed from only one carefully selected plant of this type was secured, and gave 77 plants of the F_3 generation. These gave on growing :—

Long broad-lobed leaves	..	None
Long narrow-lobed leaves	..	1
Short broad-lobed leaves	..	1
Short narrow-lobed leaves	..	75

This was, as would have been expected, from a pure recessive type.

The F_4 generation, which has been taken in 1921-22, enables us to go a stage further in this discussion.

Seed obtained from the following plants were used for cultivation.

I. *Long broad-lobed plants.*

(a) Seed from 13 plants of the F_3 generation, the history of whose parentage is as follows :—

F_1 . *Long broad-lobed leaves.*

F_2 . *Long broad-lobed leaves.*

F_3 . All *long broad-lobed leaves.*

(b) Seed from 8 plants of the F_3 generation, the history of whose parentage is as follows :—

F_1 . *Long broad-lobed leaves.*

F_2 . *Long broad-lobed leaves.*

F_3 . All variations found, but *long broad-lobed leaves* selected for producing the seed in the present case.

(c) Seed from 7 plants of the F_3 generation, the history of whose parentage is as follows :—

F_1 . *Long broad-lobed leaves.*

F_2 . *Long broad-lobed leaves.*

F_3 . Only long broad and short broad-lobed leaves found but *long broad-lobed leaves* selected for producing the seed in the present case.

The results of growing the seed were as follows :—

(a) *From thirteen plants with pure long broad-lobed leaves.*

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	66	66	..	..	..	1.0	..	..	..
2 ..	94	91	..	3	..	0.97	..	0.03	..
3 ..	81	79	..	2	..	0.97	..	0.03	..
4 ..	77	77	..	..	..	1.0	..	..	..
5 ..	94	93	..	1	..	0.99	..	0.01	..
6 ..	118	118	..	..	..	1.0	..	..	..
7 ..	95	94	..	1	..	0.99	..	0.01	..
8 ..	90	90	..	..	..	1.0	..	..	..
9 ..	103	103	..	..	..	1.0	..	..	..
10 ..	89	89	..	..	..	1.0	..	..	..
11 ..	71	68	3	..	..	0.96	0.04	..	..
12 ..	103	98	2	3	..	0.95	0.02	0.03	..
13 ..	75	66	3	6	..	0.88	0.04	0.08	..

The plants are therefore substantially pure types with a long broad-lobed leaf, and breed pure. Plant No. 13 seems a little aberrant, but it has not been possible so far to follow this up.

(b) *From eight plants from a family in the F_3 generation which contains all four varieties in leaf shape.*

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	129	74	22	26	7	10.5	3.1	3.7	1.0
2 ..	114	65	18	24	7	9.2	2.6	3.4	1.0
3 ..	135	93	..	42	..	3.1	..	1.0	..
4 ..	103	..	103	..	..	..	1.0	..	..
5 ..	74	41	10	19	4	10.2	2.5	4.1	1.0
6 ..	103	..	..	103	..	..	..	1.0	..
7 ..	109	43	26	34	6	7.1	4.3	5.6	1.0
8 ..	83	35	21	22	5	7.0	4.2	4.5	1.0

In this case it is obvious that Nos. 1, 2, 5, 7, and 8 still contain elements of all four possible varieties, and the proportion of these is as follows, taken together :—

L. B. : L. N. : S. B. : S. N. :: 8.9 : 3.4 : 4.3 : 1,

This is not the exact Mendelian ratio to be expected, but is very close to it. In No. 3 the parent appears to contain the "broad" character exclusively as no narrow-leaved plants are found among the progeny, but it has elements of "length" and "shortness" as previously defined, and the proportion of "long-broad" to "short-broad" lobed leaves is again almost exactly what would be expected in dealing with a simple Mendelian factor. In the case of Nos. 4 and 6, the parent appears to be pure as to leaf character, as all the progeny in the former case have long narrow-lobed leaves and in the latter short broad-lobed leaves.

(c) *From seven plants from a family in the F₃ generation, which contains "long-broad" and "short-broad" elements.*

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	101	1	..	100	..	..	..	1.0	..
2 ..	107	82	..	25	..	3.2	..	1.0	..
3 ..	91	..	..	91	..	..	..	1.0	..
4 ..	86	66	..	20	..	3.3	..	1.0	..
5 ..	101	..	..	101	..	..	..	1.0	..
6 ..	93	70	..	23	..	3.0	..	1.0	..
7 ..	111	5	..	106	..	0.04	..	0.96	..

In the results of this generation we get, therefore, a total absence of narrow leaves as we should expect. Three plants out of the seven have given a progeny with both "long-broad" and "short-broad" lobed leaves in the following proportion:—

L.B. : S.B. :: 3.3 : 1.

This is again almost the expected ratio for two simple Mendelian factors. The remaining plants have produced progeny with almost only short broad-lobed leaves. The only exceptions are five plants out of 111 in No. 7 above, whose history can be followed up in the next generation and a possible explanation found. The whole of these five apparently aberrant plants are only very slightly over the boundary of 'shortness', four being four per cent. above and the fifth being nine per cent. above.

II. *Long narrow-lobed plants.*

In this case seed was taken from six plants of the F₃ generation derived from parents in the F₂ generation which only produced progeny with *long*

narrow-lobed leaves. These were cultivated in order to see whether the apparent purity in the F_3 generation was maintained in the F_4 generation.

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	96	..	94	..	2	..	..	..	..
2 ..	75	..	75	..	..	..	..	..	..
3 ..	74	..	71	..	3	..	1	..	..
4 ..	91	2	88	..	1	..	..	..	..
5 ..	99	..	98	..	1	..	..	..	..
6 ..	58	..	58	..	..	..	..	..	..

It is evident therefore that the purity of the strain is maintained, the few aberrant forms being only slightly over or under the selected boundary of shortness respectively. Thus of the three plants marked as 'long-broad' the actual breadth measurements were as follows:—

(a) Limit of breadth for narrow leaves		..	..	30 mm.
(Plant 1)	0.1 ..	..	..	33 "
(Plant 4)	0.2 ..	..	..	33 "
	0.3 ..	..	..	33 "
(b) Limit of length for short leaves		..	..	66 "
(Plant 1)	0.1 ..	..	..	63 "
	0.2 ..	..	..	60 "
	0.3 ..	..	..	63 "
(Plant 3)	0.4 ..	..	..	63 "
	0.5 ..	..	..	63 "
(Plant 4)	0.6 ..	..	..	60 "
(Plant 5)	0.7 ..	..	..	63 "

III. *Short narrow-lobed plants.*

In this case seed was taken from two plants of the F_3 generation. These were derived from plants in the F_2 generation which only gave progeny with short narrow-lobed leaves. It formed, in fact, a test of the real purity or otherwise of the apparently pure recessive type in the F_3 generation by growing the whole of progeny.

No.	No. of plants	Plants with lobes				Proportion			
		Long broad	Long narrow	Short broad	Short narrow	Long broad	Long narrow	Short broad	Short narrow
1 ..	69	..	..	..	69	..	..	..	1
2 ..	93	..	..	1	92	..	..	..	1

The one plant which ranks as short broad was only 33 mm. broad, the limit for narrow leaves being 30 mm. It hardly, therefore, exceeded the limit, and the whole of the progeny of the two test plants remained pure, as would be the case if we are dealing with a pair of recessive characters.

The conclusions obtained from a consideration of the F_4 generation, therefore, substantially confirm those reached in the previous year.

In summary, regarding the shape of the leaf considered as a hereditary character in the cross between the strains of *Gossypium herbaceum* and *Gossypium neglectum* described above, it may be stated—

(1) That the "leaf-factor" introduced by Leake as a single figure to represent the shape of the leaf would seem to be complex, as variability of the length and breadth of the middle lobe is greater than that of its factors, and the correlation between these latter is only slight, the co-efficient of correlation being only 0.28.

(2) That, provided the plants are grown under the same conditions, in the same year, and that similarly placed leaves are taken for the measurements, the length and the breadth of the middle lobe of the leaf are single hereditary characters varying independently.

(3) That the broad-lobed leaf of the Dharwar No. I parent is dominant over the narrow-lobed leaf of the *rosea* parent and the long-lobed leaf of *rosea* is dominant over the short-lobed leaf of Dharwar No. I. The F_1 generation consists therefore entirely of long broad-lobed leaves, the range of length extending, however, beyond the longest leaf of the *rosea* parent.

(4) That in the F_2 generation the splitting of the cross occurs in almost the Mendelian ratio for two independently varying characters, namely:—

Long broad-lobed leaves	..	8.3
Long narrow-lobed leaves	..	3.3
Short broad-lobed leaves	..	3.4
Short narrow-lobed leaves	..	1.0

(5) That in the F_3 and F_4 generations the splitting of the cross continues and the descendants of the various types of plant in the F_2 generation again almost exactly correspond with what would occur with two independently varying Mendelian characters. The variation from the theoretical figures are not large, but later on it is hoped to investigate the reason for them.

(C) COLOUR OF FLOWER.

The previous work on the colour of the flower as a hereditary character has been referred to in Chapter I. Fletcher found that in crosses between yellow flowers and white flowers the former proved a dominant character, a

conclusion which was verified by Fyson. Balls, on the other hand, found that the inheritance of colour of flower was complex, but he was not able to elucidate its character completely. Leake again very closely investigated the matter on the basis of the crosses he made between strains of *Gossypium arboreum* (*narma*) and *Gossypium neglectum*. He distinguishes between two kinds of yellow colour, a full yellow and what he terms "pale yellow." He states¹: "The yellow colour is dependent on a colour producing factor, which, according to its presence or absence, gives rise to a simple pair of allelomorphic characters, of which the presence of the colour producing factor is dominant in both cases. That is, the yellow is dominant both to pale yellow and to white." He adds: "In the present, therefore, it is impossible to say what relations exist between the two conditions which may be indicated by the presence and absence of the pale yellow factor. . . . It is clear, however, that this condition does not correspond with that denoted by Balls as lemon yellow, which he found to represent the impure stage in the cross between full yellow and white flowered parent in the Egyptian cottons." Since the publication of the memoir by Leake and Ram Prasad from which these extracts are made, there appear to have been no further publications on the subject.

The author's cross was between a full yellow-flowered type (Dharwar No. 1) and a pure white-flowered type (*rosea*), and the resulting crosses have given very interesting results, which may now be detailed.

(1) In the F₁ generation the whole of the plants obtained gave pale yellow flowers. The actual difference in colour between the parents and the F₁ generation is shown by the following analysis of the colours on Lovibond tintometer.

Frequency distribution of colour.

Lovibond's degrees (Yellow)					Dharwar No. I	<i>Rosea</i>	F ₁ generation
5.0	..	..	..	..	..	..	1
5.25	..	..	..	..	..	..	20
5.5	..	..	..	..	..	..	49
5.75	..	..	..	..	..	..	30
6.0	..	..	..	..	..	..	..
6.25	..	..	..	..	..	..	..
6.5	..	..	..	..	4	..	..
6.75	..	..	..	..	21	..	..
7.0	..	..	..	..	45	..	..
7.25	..	..	..	..	26	..	..
7.5	..	..	..	..	4	..	..

¹ Leake and Ram Prasad. Studies in Indian Cottons. *Mem. Dept., Agri. India, Bot. Ser.*, Vol. VI, No. 4, page 126 (1914).

(2) In the F_2 generation out of a total of 1,057 plants, the colours were as follows :—

	No. of plants	Proportion
Pale yellow	643	3.9
Full yellow	162	1.0
White	252	1.6

There was no difficulty in distinguishing these colours in the morning soon after they opened. If the examination was delayed until the late afternoon, a certain amount of fading of the yellow colour had occurred, and it was not so easy to distinguish the colours. Hence all examinations were made in the morning soon after the flowers opened.

It is obvious that the colour of the flower is not a single Mendelian factor in which the pair is (1) colour and (2) absence of colour, but it is difficult, on the basis of the characters in the F_2 generation only, to understand clearly how the actual colours found are composed. The F_3 generation gives, however, some light on this point.

(3) For the F_3 generation seed from 32 plants of the F_2 generation was planted. Of these—

17 plants were pale yellow in the F_2 generation.

10 plants were full yellow „ „ „

5 plants were white. „ „ „

Let us consider the way in which these behave.

(a) All the plants which had white flowers in the F_2 generation also yielded white flowers in the F_3 generation as follows :—

Serial No.	Total number of plants	Pale yellow	Full yellow	White
1	68	nil	nil	68
2	74	nil	nil	74
3	81	nil	nil	81
4	43	nil	nil	43
5	102	nil	nil	102

(b) All plants which had *full yellow* flowers in the F_2 generation gave flowers of varying colours in the F_3 generation as follows :—

Serial No.	Total number of plants	Pale yellow	Full yellow	White	Proportion		
					Pale yellow	Full yellow	White
1 ..	71	..	71	..	0	1.0	0
2 ..	67	..	67	..	0	1.0	0
3 ..	58	..	58	..	0	1.0	0
4 ..	63	16	47	..	1	2.9	0
5 ..	57	12	45	..	1	3.7	0
6 ..	73	24	49	..	1	2.0	0
7 ..	72	21	51	..	1	2.4	0
8 ..	73	16	57	..	1	3.6	0
9 ..	58	0	42	16	0	2.6	1
10 ..	68	0	49	19	0	2.5	1

(c) The plants which had *pale yellow* flowers in the F_2 generation gave flowers of varying colour in the F_3 generation as follows :—

Serial No.	Total number of plants	Pale yellow	Full yellow	White	Proportion		
					Pale yellow	Full yellow	White
1 ..	68	68	..	..	1.0	0	0
2 ..	68	66	2	..	1.0	0	0
3 ..	61	49	0	12	4.0	0	1
4 ..	74	58	0	16	3.6	0	1
5 ..	69	51	0	18	2.8	0	1
6 ..	75	60	0	15	4.0	0	1
7 ..	81	59	0	22	2.7	0	1
8 ..	66	48	18	..	2.6	1	0
9 ..	75	54	21	..	2.5	1	0
10 ..	76	64	12	..	5.3	1	0
11 ..	63	46	17	..	2.7	1	0
12 ..	75	51	24	..	2.1	1	0
13 ..	66	46	20	..	2.3	1	0
14 ..	79	45	11	23	4.0	1	2.0
15 ..	78	48	12	18	4.1	1	1.5
16 ..	61	34	10	17	3.4	1	1.7
17 ..	59	32	9	18	3.6	1	2.0

It is obvious, therefore, that the white colour is a pure recessive character in the crossing of these two types, as the whole of those plants which had white flowers in the F_2 generation bred true in this character. The constitution of the yellow-flowered plants was, however, more complicated and it could not

be pretended that the constitution of the colour of these flowers had been completely deciphered. The matter was, therefore, further examined in the F_4 generation.

(4) For the F_4 generation seed from 34 plants of the F_3 generation was planted. Of these—

12 plants were pure white in F_2 and F_3 generations.

13 plants were full yellow in F_2 and F_3 generations.

9 plants were pale yellow in F_2 and F_3 generations.

These behaved as follows :—

(a) All the plants which had white flowers in the F_2 and F_3 generations also yielded white flowers in the F_4 generation.

Serial No.	Total number of plants	Pale yellow	Full yellow	White
1 ..	53	..	..	53
2 ..	82	..	..	82
3 ..	49	..	..	49
4 ..	63	..	..	63
5 ..	71	..	..	71
6 ..	47	..	..	47
7 ..	101	..	..	101
8 ..	94	..	..	94
9 ..	82	..	..	82
10 ..	78	..	..	78
11 ..	63	..	..	63
12 ..	82	..	..	82
	865			865

(b) The plants which had *full yellow* flowers in the F_2 and F_3 generations gave flowers of varying colours in the F_4 generation as follows :—

Serial No.	Total number of plants	Number of plants with colours			Proportion		
		Pale yellow	Full yellow	White	Pale yellow	Full yellow	White
1 ..	85	..	85	..	..	1	..
2 ..	101	..	101	..	..	1	..
3 ..	93	..	93	..	..	1	..
4 ..	114	..	114	..	..	1	..
5 ..	72	..	72	..	..	1	..
6 ..	81	..	81	..	..	1	..
7 ..	110	..	110	..	..	1	..
8 ..	120	..	120	..	..	1	..
9 ..	116	15	101	..	1	6.7	..
10 ..	82	24	44	14	1.7	3.1	1
11 ..	69	8	54	7	1.1	7.7	1
12 ..	68	3	62	3	1	20.6	1
13 ..	58	5	50	3	1.6	16.6	1

Now all the plants (Nos. 1—8), which yielded full yellow-flowered progeny only, were derived from plants of the F_2 generation which likewise yielded full yellow-flowered progeny only. So that in these eight cases there is a record of full yellow-flowered plants only for three generations, and hence this colour seems to be hereditary as a single character, which may, however, be simple or compound.

The remainder of the plants, derived from F_2 plants with full yellow flowers which yielded both pale and full yellow-flowered progeny in the F_3 generation, all gave descendants varying in this character. In one case (No. 9) only pale yellow and full yellow progeny were produced in the previous generation, though the proportion of full yellow plants is now much higher as follows :—

		Pale yellow	Full yellow
F_3 ..	..	1	3.7
F_4 ..	..	1	6.7

In the remaining cases all three types of colour appeared in the progeny but in very different proportion, so different in fact that it is difficult to believe that we are dealing with simple colour characters at all.

(c) The plants which had *pale yellow* flowers in the F_2 and F_3 generations gave flowers of varying colours in the F_4 generation as follows :—

Serial No.		Total number of plants	Number of plants with colours			Proportion		
			Pale yellow	Full yellow	White	Pale yellow	Full yellow	White
1	..	136	104	..	32	3.2	..	1.0
2	..	80	56	..	24	2.4	..	1.0
3	..	98	73	8	17	9.1	1.0	2.1
4	..	93	59	12	22	4.9	1.0	1.8
5	..	72	43	5	24	8.6	1.0	4.8
6	..	104	57	47	..	1.2	1.0	..
7	..	143	118	25	..	4.5	1.0	..
8	..	102	45	36	21	2.1	1.7	1.0
9	..	113	73	17	23	4.3	1.0	1.5

These figures show an extraordinary complexity in the colour character of the pale yellow flowers. It may be of interest to examine the parentage

from the F_2 generation of these plants. For this purpose there are four groups as follows :—

Nos. 1 and 2.

- F_2 Pale yellow plants, gave in.
- F_3 Pale yellow plants only.
- F_4 Pale yellow and white plants in proportion of 2·8 pale yellow to 1 white.

Nos. 3, 4 and 5.

- F_2 Pale yellow plants, gave in.
- F_3 Pale yellow and white plants, in proportion of 4·0 pale yellow to 1 white.
- F_4 Plants of all three colours in proportions varying in each case.

Nos. 6 and 7.

- F_2 Pale yellow plants, gave in.
- F_3 Pale yellow and full yellow plants in proportion of 2·6 pale yellow to 1 full yellow.
- F_4 Pale yellow and full yellow plants only but in widely different proportions.

Nos. 8 and 9.

- F_2 Pale yellow plants, gave in.
- F_3 Pale yellow, full yellow and white plants in proportion of 4 pale yellow to 1 full yellow and 2 white.
- F_4 Pale yellow, full yellow and white plants in widely different proportions in the two cases.

It is obvious, therefore, that we are in face of a much more complex character in the colour of the flowers of the cotton plant than has hitherto been thought, and the studies made so far will have to be extended considerably before it will be possible to elucidate the question. Two or three points are, however, clear. Thus it seems proved that the pale yellow colour of the flowers of some plants is not in any sense a mere blending of the full yellow colour of one of the parents into the white of the other. The three colours have, in fact, distinct characters of their own. All white-flowered plants will breed true in colour of flower. Some of the full yellow plants will do so, but others will give progeny with both pale yellow and full yellow flowers or with flowers of all three colours. The full yellow colour can, however, be fixed as a hereditary character. Plants with pale yellow flowers have never bred true in this colour character, and the progeny may be a mixture of pale yellow and white, of pale yellow and full yellow, or of all three colours in widely differing proportions.

Beyond this little can be said, and it will need a good deal more study than the author has yet been able to make, taking account of the various tints involved, before the very complicated inheritance of the colour character of the flower of the cotton plant can be clearly made out.

(D) LENGTH OF THE FLOWER PETAL.

There appear to be two types of petal among species of the genus *Gossypium*, one of which is so small that the petal is usually completely enclosed by the bracteole and the other where the petal is so large as to go far beyond it. And this relationship to the bracteoles is considered by Leake¹ to be a sufficient definition of the size of the petal in any particular case. He considers that the two types of petal "stand in marked contrast, without intermediate form." This being the case, he noted the close linkage of the size of petal and the colour, small petals being always white and yellow petals being invariably large. The author is not aware of any other work which has been done on the question of the inheritance of the size of petal in cotton plants.

It was necessary in the author's experiments first to have a more rigid definition of the size of the large and small petals. This is necessary because the bracteoles themselves vary very widely in size, and what would be called a small petal may extend beyond the length of a small bracteole and *vice versa*. In the present work, therefore, a large petal has been defined as one more than 22 mm. in length, and a small petal as one below this limit. This is a fairly satisfactory classification though it will be noted that there is slight overlapping of the sizes in the two parents. The author, in fact, cannot confirm the statement of Leake that there are two essentially different types of petal and none of intermediate size.

The length of the petals of the two parents in the present case and also of the first generation of the cross is shown in the following table indicating the frequency of petals of different sizes in each case. The table is based on the examination of flowers from 500 plants in each case.

Length of petal.

Length		Dharwar No. I	<i>Rosea</i>	F ₁
mm.				
10-12	..	..	12	..
13-15	..	..	22	..
16-18	..	..	170	..
19-21	..	9	255	21
22-24	..	66	41	94
25-27	..	144	..	213
28-30	..	225	..	160
31-33	..	51	..	12
34-36	..	4	..	..
37-39	..	1	..	..

¹ *Jour. Genetics*, Vol. I, No. 3 (1911), p. 242.

In the Dharwar No. I parent, 1·8 per cent. of the total plants are below the line empirically fixed as that of separation between large and short petals. In the case of the *rosea* parent, 8·3 per cent. are above this line, and in the case of the cross (F_1), while the large petal is evidently a dominant character, 4·2 per cent. of the plants give flowers with petals below 22 mm. in length.

In the F_2 generation several points were noted.

(1) As would be expected from Leake's experience, the correlation between white flowers and short petals was almost, though not quite, complete. In fact, out of 252 white-flowered plants, 243 gave flowers with short petals and 9 with large petals. It is curious and very suggestive that the correlation in the cases here studied was not so complete as in those examined by Leake.

(2) The splitting of the types in the F_2 generation was very curious, and so far an explanation has not been found which will account for it. The following table shows, side by side, the frequency of the various lengths of petal in the F_1 and F_2 generations.

Length of petal.

Length			F_1	F_2 Total	F_1 White flower	F_2 Yellow flower
mm.						
10-12	..	..	..	6	5	1
13-15	..	..	..	82	63	19
16-18	..	..	..	149	60	89
19-21	..	..	21	133	16	117
22-24	..	..	94	103	3	100
25-27	..	..	213	23	1	22
28-30	..	..	160	4	0	4
31-33	..	..	12	..	..	..
34-36	..	..	..	..	..	..
37-39	..	..	..	..	..	..

The result in the F_2 generation, as already stated, seems unaccountable. Instead of the dominant large petal giving the largest proportion of large petals in this generation, only 228 plants had large petals and 643 had short petals, or a proportion of 1 to 2·8, being nearly the reverse of what had been expected.

One of the reasons by which this strange phenomenon can be explained is to be found in the fact of the high degree of correlation between the white colour of the flower and the short length of petal noted above. If, however, this were the only cause of the disturbance of the usual ratio, the expected proportion would be obtained with plants bearing flowers of other colours. But the number of large and short-petalled plants among those bearing yellow flowers (including full yellow and pale yellow) was as follows :—

Large petals	..	..	..	..	184
Short petals	..	..	..	..	316

The proportion between the large-petalled plants and the short-petalled plants is 1 to 1·71, which on the basis of present knowledge is quite unaccountable. The matter has not yet been investigated in the F_3 or F_4 generations, but this will be taken up as soon as time allows, as the problem which it opens out seems of exceeding interest.

(E) PRESENCE OF NECTARIES.

The presence of both foliar and extra floral nectaries is characteristic of *Gossypium herbaceum*, while in the case of *Gossypium neglectum* these organs are sometimes present, but sometimes completely wanting. No note appears to have been made by previous writers as to the behaviour of this feature of certain cotton varieties on crossing, and as the type of *Gossypium neglectum* used in these experiments had been totally without the glands in question for several generations, the behaviour on crossing seemed worthy of careful record.

On the cross between Dharwar No. I and *rosea* being made, it was found that the plants of the F_1 generation possessed both extra floral and foliar glands, so that the presumption is that this character is a normal Mendelian dominant.

In the F_2 generation, 1,050 plants were examined with the following results :—

Number with glands (nectaries)	..	..	743
Number without glands	..	..	307

The proportion is 2·4 to 1. This is not quite the proportion expected, and it would appear that we are not in the presence of a completely simple character. The investigation has not yet been carried further, but it may be possible to do this in the near future.

(F) GINNING PERCENTAGE.

The ginning percentage of the *kapas* is one of the most important characters of a type of cotton, and as before stated, the primary purpose for which the present cross was made was to combine the high ginning character of the *neglectum* cottons with the good staple of the *kumpta* type of *Gossypium herbaceum*.

How far the proportion of lint to seed is a hereditary character is not clear from the published record of work done on cotton breeding. The only worker on the subject who has dealt with this question is Balls,¹ and he has only considered the distribution of the lint on the seed. He finds that a regular distribution of the lint is dominant over an irregular distribution, but as regards the *amount* of lint he offers no experiments and makes no statement. The matter is, however, in the present case, of vital importance to the utility of any plants from the resulting cross.

The ginning percentage of the seeds from 100 plants of the *Gossypium*

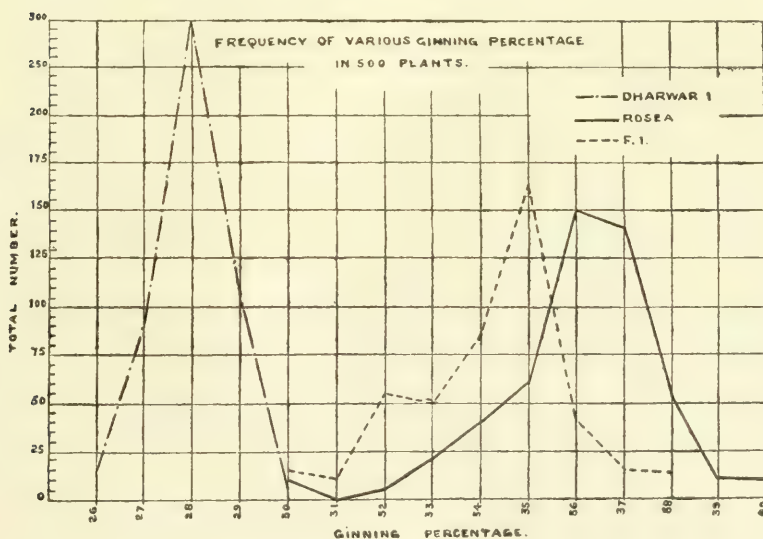


FIG. 6.

neglectum (var. *rosea*) parent has already been given in a previous chapter (page 80), but may be repeated (now calculated for 500 plants) side by

¹ *Loc cit.*, p. 145. It has been suggested that the lint index, *i.e.*, the amount of lint per 100 seeds, should be used instead of the ginning percentage. There is no advantage in doing this in the present case, as the seed weight of each of the two types is practically identical.

side with a similar table for the other parent and for 450 plants of the resulting cross (F_1) as follows :—

Ginning percentage	Dharwar No. 1	<i>Rosea</i>	F_1
26	15	..	..
27	90	..	..
28	285	..	..
29	105	..	..
30	5	10	15
31	..	..	11
32	..	5	54
33	..	20	50
34	..	40	84
35	..	60	161
36	..	150	42
37	..	140	15
38	..	55	18
39	..	10	..
40	..	10	..

The mode and mean ginning percentage in each case is as follows :—

Name of cotton	Mode per cent.	Mean per cent.
Dharwar No. 1	28	28
<i>Rosea</i>	36-37	35.1
F_1	35	34.2

It will thus be seen that the high ginning percentage of the *rosea* parent, while not apparently completely dominant, yet gives a progeny which approaches it closely in this character, and indicates that it is largely prepotent so far as this quality is concerned.

In the F_2 generation, the following table shows the number of plants with various ginning percentages, the F_1 figures being repeated for comparison.

Ginning percentage				F_1	F_2
23	..	..	..	..	6
24	..	..	..	..	13
25	..	..	..	..	20
26	..	..	..	..	11
27	..	..	..	..	22
28	..	..	..	..	31
29	..	..	..	..	23
30	..	..	..	15	72
31	..	..	..	11	51
32	..	..	..	54	41
33	..	..	..	50	82
34	..	..	..	84	24
35	..	..	..	161	35
36	..	..	..	42	30
37	..	..	..	15	19
38	..	..	..	18	2
39	..	..	..	..	1
40	..	..	..	..	13
41	..	..	..	..	2
42	..	..	..	..	1
43	..	..	..	..	1

If, by analogy with the parents, all these plants are considered as having a low ginning percentage which have a percentage of 29 or below, and all above this point as having a high ginning percentage, the proportion in the various cases considered would be as follows :—

Dharwar No. I	..	99	per cent.	low ginning
<i>Rosea</i>	..	100	..	high ginning
F_1	..	100	..	high ginning
F_2	..	25.2	..	low ginning
		74.8	..	high ginning

The proportion between the plants yielding seeds giving high (above 29 per cent.) and those yielding seeds giving low (29 per cent. and below) is 2.9 to 1, almost exactly the proportion (3 : 1) which would be expected with a simple Mendelian pair of characters in which the high ginning character is dominant over the low ginning character.

The results in the F_3 generation enable this to be further studied, but as the year of growth was different (1920-21) from that in which the above figures were obtained, the records of ginning percentage for the parents and F_1 cross grown in the same year (1920-21) must be given.

Dharwar No. I	..	26 to 29	per cent.	Mode at 28	per cent.	Mean	..	27.5
<i>Rosea</i>	..	31 to 38	..	..	at 35	..	..	34.3
F_1	..	30 to 38	..	..	at 35	..	..	34.8

The characters of the seeds from the parents and from the F_1 generation remained therefore substantially identical with those grown in the previous

year. The F_3 generation gave results as follows, using seed from the high ginning plants of the F_2 generation in 14 cases and from the low ginning plants in one case. The records of seed from these fifteen plants are as follows :—

Plant No.				Seed planted	Number of plants		Proportion	
					High ginning	Low ginning	High ginning	Low ginning
High ginning	1	..	..	78	56	22	2.5	1
	2	..	..	91	69	22	3.1	1
	3	..	..	86	67	19	3.5	1
	4	..	..	74	61	13	4.6	1
	5	..	..	90	88	2	1	0
	6	..	..	73	54	19	2.8	1
	7	..	..	77	77	0	1	0
	8	..	..	45	36	9	4.0	1
	9	..	..	87	64	23	2.7	1
	10	..	..	56	39	17	2.3	1
	11	..	..	66	46	20	2.3	1
	12	..	..	70	52	18	2.8	1
	13	..	..	76	72	4	1	0
	14	..	..	89	69	20	3.4	1
Low ginning	15	..	..	77	3	74	0	1

There are evidently two types of plants among those which gave high ginning seeds in the F_2 generation. Nos. 1-4, 6, 8-12 and 14 gave, taken together, 3.1 high ginning plants to 1 low ginning plant. Nos. 5, 7 and 13, on the other hand, gave to all intents and purposes only plants yielding high ginning seeds and appeared to be pure in this character. The progeny from the single low ginning plant sown gave substantially pure low ginning seeds. So that the records for this (F_3) generation of the parent cross confirm the idea that the high or low ginning characters behave as a simple Mendelian character, the high ginning character being dominant over the low ginning. This is an exceedingly important result, and leads to a conception that it may be possible to combine a high ginning type of seed with one of long staple, if the latter proves to be also a Mendelian character.

The F_4 generation grown in 1921-22 has enabled the study of the inheritance of the ginning percentage, or in other words, of the amount of lint per seed, to be carried a stage further. The progeny of twenty-four plants of the F_3 generation has been obtained and studied as follows :—

- (1) Four plants from the progeny of No. 5 and seven plants from the progeny of No. 7 in the above table which were presumably entirely pure in the high ginning character.

- (2) Six plants from the high ginning progeny of No. 2 and seven plants from the high ginning progeny of No. 14, which gave in the F_3 generation the Mendelian proportion of 3 high ginning to 1 low ginning descendants.

The standard of 'low' to 'high' ginning character was unchanged from that adopted in the previous year, as a further growing of the parents of the cross showed, and the results obtained were as follows :—

(1) *Pure high ginning plants of F_3 generation.*

Plant No.			Total number of plants	Number of plants		Proportion	
				High ginning	Low ginning	High ginning	Low ginning
1	..	..	49	49	..	1	..
2	..	..	36	36	..	1	..
3	..	..	41	41	..	1	..
4	..	..	44	43	1	1	..
5	..	..	54	54	..	1	..
6	..	..	32	32	..	1	..
7	..	..	43	43	..	1	..
8	..	..	45	44	1	1	..
9	..	..	41	41	..	1	..
10	..	..	70	70	..	1	..
11	..	..	54	54	..	1	..

Thus practically the whole 507 out of 509 of the plants derived from those supposed to be pure in this character in the F_3 generation have yielded purely high ginning seed. The two plants which seem exceptional gave as follows :

Limit of high ginning	..	..	30 per cent.
1	..	..	28 „
2	..	..	29 „

(2) *High ginning plants of the F_3 generation from parents yielding both high and low ginning progeny.*

Plant No.	Total number of plants	Number of plants		Proportion	
		High ginning	Low ginning	High ginning	Low ginning
1	54	36	18	2.0	1.0
2	51	40	11	3.6	1.0
3	49	38	11	3.4	1.0
4	47	37	10	3.7	1.0
5	41	33	8	4.1	1.0
6	43	42	1	1.0	..
7	51	38	13	2.9	1.0
8	31	22	9	2.5	1.0
9	26	26	..	1.0	..
10	41	32	9	3.5	1.0
11	26	21	5	4.2	1.0
12	37	27	10	2.7	1.0
13	43	42	1	1.0	1.0

Three plants have given progeny pure in the high ginning character. The remainder have given descendants with both high ginning and low ginning characters in the proportion (on the total)—

High ginning : Low ginning :: 3.1 : 1.

Only three of the plants gave progeny whose proportion was seriously different from the expected percentage of 3 to 1. These were plants Nos. 1, 5, and 11. No. 11 was in a line seriously attacked by wilt, and as in the case also of No. 8 it perhaps ought to be eliminated from the comparison. The cases of Nos. 1 and 5 are not yet understood, and the seed obtained from these plants will need further study.

But on the whole the important result derived from a study of the F_3 generation that the proportion of lint to seed is a simple Mendelian character seems confirmed, and this suggests more clearly even than before the possibility of a cotton type with high ginning character and also long staple.

One question remains, however. Have the plants, pure in the high ginning character, as high a ginning percentage on the average as the high

ginning type of the F_1 generation from which they are descended? The following table gives the result of a study of this point first in the F_3 and then in the F_4 generation.

F₃ generation (1920-21).

Ginning percentage				F_1	Progeny of F_2		
					Plant No. 5	Plant No. 7	Plant No. 13
28	..	..	..	..	..	0	1
29	..	..	..	..	2	0	2
30	..	..	..	15	0	1	8
31	..	..	..	11	1	7	12
32	..	..	..	54	3	8	12
33	..	..	..	50	15	13	22
34	..	..	..	84	13	22	14
35	..	..	..	161	19	12	2
36	..	..	..	42	22	9	1
37	..	..	..	15	9	2	1
38	..	..	..	18	4	2	1
39	..	..	..	..	2	1	..
40	..	..	..	..	0	0	..
Total				450	90	77	76
Mode	..	..	..	35	36	34	33
Mean	..	..	..	34.2	34.9	34.2	32.3

F₄ generation (1921-22).

Ginning percentage				F_1	Progeny of eleven plants
28	..	..	..	..	..
29	..	..	..	..	..
30	..	..	..	12	9
31	..	..	..	5	30
32	..	..	..	46	47
33	..	..	..	81	64
34	..	..	..	130	76
35	..	..	..	104	127
36	..	..	..	71	70
37	..	..	..	17	34
38	..	..	..	20	25
39	..	..	..	14	17
40	..	..	..	..	10
Total				500	509
Mode	..	..	..	34	35
Mean	..	..	..	34.5	34.7

The progeny, therefore, maintains both in the third and fourth generations of the cross the proportion of lint found in the high ginning type of the F_1 generation.

(G) LENGTH OF STAPLE.

In any breeding of cotton for the market, the staple of the resulting product is one of the three primary considerations. The yield of the crop in the field is perhaps the primary consideration for the farmer, the ginning percentage largely concerns the merchant who purchases seed cotton (*kapas*), but the staple of the resulting lint is what chiefly determines its market value after ginning. Hence, from the beginning, the question of improving the staple or of combining staple with other good qualities has interested workers on this question. Thus, as noted above, Fletcher¹ studied the question and found that length of lint (staple) is a dominant Mendelian character and this opinion was confirmed by Fyson. Balls also agreed on this point from his Egyptian studies, and no account of further investigations has been so far published. The studies whose progress we now record were designed to confirm (or otherwise) these observations and also to ascertain how far the staple and ginning percentage were correlated with one another.

The staple of the lint from a type of cotton is variable according to the part of the seed from which it is taken, and it becomes necessary to define exactly how the measurements were made in the present case. The actual variations in different parts of the seed in the Dharwar No. 1 type were discussed in a previous memoir, and also the variation from year to year. In the case of the other parent (*rosea*) the variation was decidedly smaller in the different parts of the seed, and the variation of the fibres in different years was as follows :—

			Dharwar No. 1	<i>Rosea</i>
			mm.	mm.
1919-20	..	..	22 to 33	12 to 21
1920-21	..	..	22 to 33	13 to 23
1921-22	..	..	24 to 36	12 to 24

In all measurements, therefore, the length of staple was judged by the fibres from the middle of the seed, and comparisons were only made between the produce of plants grown in the same season. Restricting comparisons

¹ See Chapter J, page 73.

in this way the following shows the staple of the two parents and the F_1 cross as grown (1) in 1919-20, (2) in 1920-21, and (3) in 1921-22.

		1919-20			1920-21		
		Dharwar No. 1	<i>Rosea</i>	F_1	Dharwar No. 1	<i>Rosea</i>	F_1
mm.							
10-12	..	..	20	..	..	..	..
13-15	..	..	115	..	..	81	..
16-18	..	..	335	..	..	95	..
19-21	..	..	30	..	..	220	..
22-24	..	60	..	60	21	104	12
25-27	..	180	..	225	181	..	157
28-30	..	210	..	155	223	..	277
31-33	..	50	..	60	75	..	54

		1921-22		
		Dharwar No. 1	<i>Rosea</i>	F_1
mm.				
10-12	..	..	30	..
13-15	..	..	80	..
16-18	..	..	162	..
19-21	..	..	218	..
22-24	..	15	10	2
25-27	..	145	..	133
28-30	..	235	..	262
31-33	..	105	..	83
34-36	..	..	..	20
Total	..	500	500	500

It was evident, in fact, that we had considerably different conditions prevailing in the three years quoted, 1920-21 and 1921-22 were years more favourable to long staple than 1919-20. While in 1919-20 all the low staple cotton had a lint length of below 21 mm. and all the high staple higher than this, in 1920-21 and 1921-22 the line of demarcation was at 24 mm., all the short staple cotton (*rosea*) being below this, and 96 and 97 per cent. respectively, in the two years, of the long staple cotton (Dharwar No. 1) being above. The mode and mean of the length of staple in the three years was as follows :—

		1919-20		1920-21		1921-22	
		Dharwar No. 1	<i>Rosea</i>	Dharwar No. 1	<i>Rosea</i>	Dharwar No. 1	<i>Rosea</i>
Mode of length of staple	..	mm. 30	mm. 18	mm. 30	mm. 21	mm. 30	mm. 21
Mean length of staple	..	28.5	16.8	29.2	20.0	29.4	19.2

The F_1 generation followed the length of lint of the long staple cotton and gave in the three years the following figures :—

			1919-20	1920-21	1921-22
			F_1	F_1	F_1
			mm.	mm.	mm.
Mode of length of staple	..	..	27	30	30
Mean length of staple	..	..	28.2	29.1	29.7

This showed a staple almost but not quite as long as that of the Dharwar No. I parent, and indicates the dominance of high staple over low staple between these two types of cotton.

The behaviour of the cross in the F_2 generation was peculiar, and indicated that some influence was present which prevented the distribution of the staple in accordance with what would be expected with a simple Mendelian factor. The figures obtained were in fact as follows :—

			1919-20	
			F_1	F_2
mm.				
13-15	..	..	..	19
16-18	..	..	..	67
19-21	..	..	..	132
22-24	..	..	60	144
25-27	..	..	225	106
28-30	..	..	155	31
31-33	..	..	60	1
Total	..	..	500	500

Thus we have 282 plants of long staple (*i.e.*, above 21 mm.) and 218 plants of short staple (*i.e.*, below and including 21 mm.) or a proportion of 1.6 to 1.

But at this point a reference may be made to the *colour* of *kumpta* cotton in general, and to that of Dharwar No. I in particular, which in this respect is like the rest of the variety. The cotton lint, as has already been described, is not white, but a dull white with a tinge of red, and this is continued in the

F₁ generation. But in the F₂ generation the colour segregates, and plants appear which give pure white cotton, and others which give lint with a deep brown tint. The proportion of these colours in the F₂ generation is shown in the following table.

			Proportion
(1) No. of plants grown ..	500		
(2) Plants yielding pure white cotton	180		1.5
(3) Plants yielding dull white cotton	200		1.6
(4) Plants yielding brown cotton ..	120		1.0

The distribution, it will be seen, does not conform to any simple law, but the secret both of the distribution of colour and of the relative proportion of long and short staple in the plants of this generation seems to be found in a very close connection between the brown colour and short staple in the lint. Thus of all the plants yielding brown lint, the staple of the cotton was as follows :—

				Frequency (1919-20)
mm .				
13-15				14
16-18				54
19-21				49
22-24				3
Total				120

Thus it will be noticed that 97.4 per cent. of the plants yielding brown lint also give lint which classes as short in staple, while of the remainder the lint only just exceeded the length necessary to bring it into the longer class.

Seeing that the correlation between brown colour and short staple is so complete, it may be assumed* that the presence of the brown colour has interfered with the normal operation of the Mendelian law, and that all plants which have a brown colour have been necessarily drawn into the short staple class. If from the 500 plants of the F₂ generation, the 120 plants which give a deep brown cotton are removed, the remainder give a distribution of the staple as follows :—

	Plants
Long staple (<i>i.e.</i> , over 21 mm.) ..	279
Short staple (<i>i.e.</i> , 21 mm. or below) ..	101

This gives a proportion of 2.7 to 1, or very nearly the relationship required for a single simple Mendelian factor.

* It is not suggested that this assumption is proved as it has not been possible to follow the matter further in the succeeding generations.

This argument could have been tested if in the F_3 generation only brown or dull white cottons were taken for further cultivation, but this could not be done, and only plants giving pure white coloured lint were grown in this generation. As pure white colour in the lint behaves as a pure recessive character, no further complications due to the brown element in the lint now arose.

The seeds from fifteen such plants yielding pure white lint were selected for growing in the F_3 generation, fourteen from plants yielding long staple, and one from a plant yielding a short staple cotton. The results from each of these plants as grown in 1920-21 are shown below:—

I. High stapled plants.

Plant No.	Number of seeds grown	Long staple (i.e., over 24 mm.)	Short staple (i.e., below 24 mm.)	Proportion	
				Long staple	Short staple
1 ..	90	88	2	1	..
2 ..	66	59	7	1	0.12
3 ..	89	89	..	1	..
4 ..	77	77	..	1	..
5 ..	78	60	18	3.3	1
6 ..	91	67	24	2.8	1
7 ..	86	62	24	2.6	1
8 ..	84	67	17	3.9	1
9 ..	73	51	22	2.3	1
10 ..	77	58	19	3.0	1
11 ..	87	62	25	2.5	1
12 ..	56	31	25	1.2	1
13 ..	70	48	22	2.2	1
14 ..	76	59	17	3.5	1

II. Low stapled plant.

15 ..	45	1	44	0	1
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If plant No. 2 above be eliminated, and possibly also plant No. 12, where the number of successful plants is small and hence the proportion is likely to be unsatisfactory, we have :—

- (1) Three plants apparently pure as to high staple.
- (2) Nine plants giving both long and short staple progeny in the proportion, on the average, of 2·9 to 1, or very nearly the expected Mendelian ratio, if long staple is a pure dominant.

From a plant yielding pure white cotton and giving short staple lint, the progeny was entirely short staple and pure white. In other words, both these characters behave as pure Mendelian recessive characters.

It appears, moreover, that once the brown coloured cottons are eliminated, the staple behaves as a simple Mendelian character.

All the plants giving purely what have been called long stapled cottons are not, however, equal as the following statement of the length of the staple in three such cases showed.

			Plant 1	Plant 3	Plant 4	F ₁
mm.						
22-24	..	..	2	0	0	12
25-27	..	..	60	64	25	157
28-30	..	..	25	25	42	277
31-33	..	..	3	0	8	54
34-36	..	..	0	0	2	0
			90	89	77	500
			mm.	mm.	mm.	mm.
Mode	..	..	25-27	25-27	28-30	30
Mean	..	..	27·9	27·8	29·3	29·1

Thus only in plant No. 4 is there no sign of regression. The others show decided symptoms of reduction in staple from that reached by the dominant parent (Dharwar No. I) or the F₁ generation grown in the same year. Exactly what this means is not clear, but the study of the F₄ generation in 1921-22 has enabled further light to be thrown on the subject.

In the F₄ generation the whole of the seed produced by twenty-four plants of the F₃ generation was grown. Of these fourteen were from plants (Nos. 1 and 3 in the table on page 126) which in the F₃ generation appeared to breed entirely true in the long staple character. The remainder, ten in number, were from plants (Nos. 5 and 6 in the table) which while giving them-

selves long staple cotton, were from parents which also gave short staple producing plants. The results are shown in the following two tables:—

I. *Progeny of plants apparently pure in long staple character.*

Plant No.	Number of plants	Long staple (over 24 mm.)	Short staple (under 24 mm.)
<i>From Plant No. 1.</i>			
1 ..	53	50	3
2 ..	51	49	2
3 ..	48	46	2
4 ..	47	42	5
5 ..	41	38	3
6 ..	43	41	2
7 ..	51	51	0
<i>From Plant No. 3.¹</i>			
8 ..	54	54	0
9 ..	32	32	0
10 ..	43	43	0
11 ..	45	42	3
12 ..	41	41	0
13 ..	70	68	2
14 ..	54	52	2

In the case of the results derived from Plant No. 1, the proportion of short staple plants seems higher than might be expected, but the whole of those so classed had a staple between 22 and 24 mm. and so really came within the range of the original long staple parent in the 1921-22 season. If this is taken into account, it may be said that the whole of the progeny of these two plants, apparently pure for staple characters in the F_3 generation, prove to retain that character in the succeeding year.

II. *Progeny of plants not pure in the long staple character.*

Plant No.	Number of plants	Long staple (over 24 mm.)	Short staple (under 24 mm.)
<i>From Plant No. 5.</i>			
1 ..	49	37	12
2 ..	36	29	7
3 ..	41	41	..
4 ..	34	27	7
<i>From Plant No. 6.</i>			
5 ..	31	24	7
6 ..	26	24	2
7 ..	41	30	11
8 ..	26	19	7
9 ..	37	29	8
10 ..	43	43	..

We have therefore a splitting taking place. Nos. 1, 2, 4, 5 and 7, 8 and 9 still retain both the long and short staple character, the proportion being :—

Long staple : Short staple :: 3·3 : 1.

This is close to the expected Mendelian ratio. The remainder (Nos. 3, 6 and 10) are pure in the long staple character and breed true.

The result, therefore, of these cultures in the F_4 generation is to confirm the conclusions already reached by a study of the previous one. The staple character is hereditary, and provided disturbing characters such as that of the brown colour of the lint are excluded the long staple character is dominant in these cottons, as was long ago claimed by Fletcher, Fyson and Balls.

But is there any regression from the standard of the F_1 generation ? This was, as has already been noted, suspected from the results of 1920-21 (F_3). But this year there is little sign of it as the following cases show :—

	Progeny of Plant No. 1	Progeny of Plant No. 2	F_1
mm.			
22-24 ..	17	7	2
25-27 ..	139	121	133
28-30 ..	172	187	262
31-33 ..	5	26	83
34-36 ..	0	0	20
Mode ..	30	30	30
Mean	28·6	29·4	29·7

(H) CORRELATION BETWEEN GINNING PERCENTAGE AND STAPLE.

It is always assumed by practical men who are working with Indian cottons, that there is a definite correlation between a high ginning type of cotton and a low staple and *vice versa*, or in other words that it is difficult if not impossible to obtain a long staple cotton which has also a high ginning percentage. Although there is no direct evidence that there is any necessity for this, it is curious to see how nearly all if not all the long staple cottons have, in fact, a small ginning percentage, and to this extent the opinion is justified by existing facts. But the characters of the cross now being studied seem to throw some light on the question, and hence the relationship between the two characters in the F_2 , F_3 and F_4 generations may be given.

In the F_2 generation the general distribution of staple and ginning percentage is shown in Fig. 7. It will be remembered that the Dharwar No. 1 parent had long staple and a low ginning percentage, the

		STAPLE							
		SHORT				LONG			
		.5	.6	.7	.8	.9	1.0	1.1	
LOW	GINNING PERCENTAGES.	22	1	2	-	1	-	-	
	23	-	-	3	2	1	-	-	
	24	1	2	2	1	3	1	-	
	25	2	3	3	1	7	9	-	
	26	1	4	3	3	4	1	-	
	27	1	3	3	4	8	7	-	
	28	1	2	-	1	21	13	-	
	29	-	4	3	5	11	2	1	
		III				IV			
		30	4	13	8	7	29	29	-
HIGH		31	6	5	11	8	30	19	-
		32	3	6	10	4	14	25	-
		33	5	7	11	33	46	5	-
		34	-	8	3	9	11	4	-
		35	2	7	4	15	18	4	-
		36	-	4	3	8	19	4	-
		37	3	2	3	8	8	1	-
		38	1	-	-	2	-	-	-
		39	-	-	-	-	2	-	-
		40	-	1	2	2	5	1	-
		41	-	-	-	-	3	-	-
		42	-	-	-	2	-	-	-
		43	-	-	-	-	2	-	-

FIG. 7.

rosea parent had short staple and a high ginning percentage, and the F_1 generation of the cross had long staple and a high ginning percentage. In the

F₂ generation the plants obtained were in the following proportion, excluding the plants producing brown tinted cotton referred to above.

Total number of plants	..	..	..	673
(1) High ginning and long staple	..	..	..	391
(2) High ginning and short staple	..	..	..	132
(3) Low ginning and long staple	..	..	..	106
(4) Low ginning and short staple	..	..	..	44

The proportion between these types was therefore

(1): (2): (3): (4) as 8·8: 3·0: 2·5: 1.

This is almost exactly the proportion which would be expected if we had to deal with two simple characters varying independently, and does not suggest any close correlation between the ginning quality and the "staple" character. The coefficient of correlation works out as 0·05, or in other words the characters are varying independently.

This is confirmed by the behaviour in the F₃ generation, where a series of plants have been grown from parents which were of high ginning and long staple character in the F₂ generation, but which contained elements both of high and low ginning, and of long and short staple in their genetic composition. The relation between the plants of various characters is shown in the following table :—

Plant No.		Total plants	Number of plants				Proportion			
			H. G. L. S.	H. G. S. S.	L. G. L. S.	L. G. S. S.	H. G. L. S.	H. G. S. S.	L. G. L. S.	L. G. S. S.
1	..	78	43	13	17	5	8·6	2·6	3·4	1·0
2	..	91	51	18	16	6	8·5	3·0	2·6	1·0
3	..	86	48	19	14	5	9·6	3·8	2·4	1·0
4	..	84	49	12	18	5	9·8	2·4	3·6	1·0
5	..	73	36	18	15	4	9·0	4·5	3·7	1·0
6	..	87	44	20	18	5	8·8	4·0	3·6	1·0
7	..	70	34	18	14	4	8·5	4·5	3·5	1·0
Total	..	569	305	118	112	34	9·0	3·2	3·3	1·0

The proportion on this total is, therefore, as follows :—

High ginning and long staple	..	..	..	9·0
High ginning and short staple	..	..	..	3·2
Low ginning and long staple	..	..	..	3·3
Low ginning and short staple	..	..	..	1·0

This again is almost exactly the proportion which would be expected if we had to deal with two simple characters varying independently, and does not suggest any close correlation between the ginning quality and the staple characters.

The results obtained in the F_4 generation are equally in agreement with this conclusion. In this case four groups of plants were examined, whose genetic constitution with regard to the features under consideration were known from their behaviour in the previous generation. The results of growing the progeny of these four groups of plants were as follows :—

I. *Parents which, in the F_3 generation, appeared genetically pure in high ginning and long staple characters.*

Total number of plants	..	..	..	339
(1) High ginning and long staple	..	..	..	332
(2) High ginning and short staple	..	..	..	6
(3) Low ginning and long staple	..	..	..	none
(4) Low ginning and short staple	..	..	..	1

Substantially all gave progeny pure in the characters carried by the plants.

II. *Parents which, in the F_3 generation, appeared genetically pure in high ginning character, but not in staple character.*

Total number of plants	..	..	..	145
(1) High ginning and long staple	..	..	..	114
(2) High ginning and short staple	..	..	..	31
(3) Low ginning and long staple	..	..	..	none
(4) Low ginning and short staple	..	..	..	none

Low ginning plants are totally absent in the progeny and the proportion of

Long staple to short staple is 3·7 to 1.

This is a little higher than the expected ratio, but the number of plants involved is small.

III. *Parents which, in the F_3 generation, appeared genetically pure in long staple character, but not in ginning character.*

Total number of plants	..	..	..	292
(1) High ginning and long staple	..	..	..	221
(2) High ginning and short staple	..	..	..	none
(3) Low ginning and long staple	..	..	..	71
(4) Low ginning and short staple	..	..	..	none

Short staple plants are absolutely absent in the progeny and in long staple plants high ginning and low ginning are present in the proportion of 3.1 to 1.

This is practically identical with the expected ratio.

IV. *Parents which, in the F_3 generation, appeared genetically pure neither in ginning nor in staple characters.*

Total number of plants	..	..	135
(1) High ginning and long staple	..	..	78
(2) High ginning and short staple	..	..	24
(3) Low ginning and long staple	..	..	24
(4) Low ginning and short staple	..	..	9

The proportion between these types was, therefore,

(1): (2): (3): (4) as 8.7: 2.7: 2.7: 1.

We are entitled, therefore, as a result of our studies of four generations of the cotton cross between pure lines of *Gossypium herbaceum* (Dharwar No. I) and *Gossypium neglectum* var. *rosea* to consider that both the ginning and the staple characters of cotton are hereditary, and that they behave as genetically independent characters. This is a conclusion of very great importance, as, if it proves generally true, it would seem to make possible the development of high ginning types of cotton with long staple, and if this can be done it will bring into the range of probability very much higher returns from many Indian cottons than have hitherto been deemed likely. Such cottons will at once satisfy the demands of the cotton trade for a good staple cotton, and of the cultivators for one which gives a large percentage of lint to the seed cotton.

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